# Assessing the Impact of Environmental Conditions and Hydropower on Population Productivity for Interior Columbia River Stream-type Chinook and Steelhead Populations

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# Table of Contents

# Table of Figures

# List of Tables

# I. Introduction

Seven Evolutionarily Significant Units (ESUs) of salmon and steelhead are listed as endangered or threatened under the Endangered Species Act in the Interior Columbia Basin. Two current, large-scale decision-making processes in the region will affect the future status of these ESUs. First, the ongoing process of developing a Biological Opinion for the Federal Columbia River Power System (FCRPS, currently in remand) will establish FCRPS operations having the potential to affect salmonid survival. Second, local, state and federal agencies are developing recovery plans for these ESUs. These plans seek to identify strategies that would improve population status and ultimately achieve recovery goals. Fundamental to both processes will be an understanding of the current status of the populations and ESUs in the interior basin, and a sense of the magnitude of change that might result from human or natural causes.

Primary among these potential influences or causes of change for current planning purposes are changes anticipated in the operation of the FCRPS, and the potential range of climatic or environmental conditions. Ocean conditions have been shown to be linked to survival of salmonids in the ocean (Mantua et al. 1997) and ocean conditions have a potentially profound effect on the viability of the Snake River spring/summer Chinook ESU (Zabel et al. 2006), and likely other ESUs as well. The hydropower system, like ocean conditions, affects all interior Columbia ESUs, and changes to this system, intended to improve survival for juvenile outmigrants and adult migrating spawners have been a key part of conservation and recovery efforts for these listed species.

In this report, we describe and present the results from a life-cycle modeling framework designed to evaluate population productivity and abundance under alternate scenarios of hydropower operation and environmental conditions. This approach translates life-stage specific changes in survival into metrics of population viability, which can be used for managing population recovery. Further, the approach takes into account the potential effects of density dependence when incorporating changes in survival. Finally, the approach allows for the analysis of alternative future scenarios, particularly ones related to climate, in the prediction of future population trajectories. The stochastic nature of the model naturally produces uncertainty in projected viability metrics.

Given the ongoing negotiations about the operations of the federal hydropower system, the motivation for exploring the impact of alternative hydropower scenarios on salmonid population status is obvious. Moreover, understanding the relative role that changes to mortality related to migration through the hydropower system can play in achieving recovery or viability goals is a critical component of crafting a robust recovery strategy. The results described in this report include analyses of the potential impact of changes in life stage survivals associated with proposed hydropower actions as estimated through the COMPASS modeling exercise (FCRPS BiOp 2007), which currently includes both direct mortality and latent mortality related to arrival timing. Our modeling framework does not explicitly consider any additional latent mortality that may be attributable to the hydrosystem (Schaller and Petrosky 2007). While some degree of this indirect mortality likely exists, its magnitude is not practical to measure directly (Independent Science Advisory Board 2007). As a next step we will conduct a sensitivity analysis for this mortality. (See Discussion). The framework we have developed is flexible enough to incorporate alternative approaches for life stage survival estimates, latent mortality and future estimates of hydrosystem mortality.

We also evaluate the magnitude of change in abundance and productivity likely under a range of environmental conditions. Recent oceanographic studies (Francis and Hare 1994, Mantua et al. 1997) and life-cycle modeling (Zabel et al. 2006) have provided more information supporting the large effect of climatic[1] and related ocean conditions during the salt-water residence, particularly the early salt-water residence, on overall survival of these fishes. These conditions are felt in two life stages. In general, conditions that lead to substantial snowpack and higher levels of runoff (flow) in the spring and summer tend to be associated with higher survival for juvenile salmon (Williams et al. 2005). In the ocean, there is a largely bottom-up process in which upwelling brings nutrients to the surface. These nutrients support increased phytoplankton growth (Brodeur and Ware 1992), and thus zooplankton and forage fish abundance, which support salmonids (Pearcy 1992, Gargett 1997). The intensity of upwelling is linked to seasonal wind patterns as well as longer-term cycles such ad El Nino/La Nina and the Pacific Decadal Oscillation (PDO). The PDO has been linked explicitly to salmonid abundance and productivity, with Columbia River stream-type salmonids showing a negative association with “warm” phases of the PDO (Mantua et al. 1997). In addition, Scheuerell and Williams (2005) have shown an association between recruitment and April upwelling and October downwelling on an annual basis. In this case, higher productivity is associated with

[1] Note that for convenience in this document we use “climate” to refer to both relatively long-term events and cycles, and any shorter-term cycles and events that are termed “weather.”

conditions that likely lead to greater biomass of zooplankton. While the precise mechanisms are still being explored, it is clear that environmental factors at a variety of scales can affect Columbia River salmonid productivity. We modeled a range of scenarios – both favorable and unfavorable for these fishes – from the historical record.

Importantly, this is a modeling exercise. As such, it can inform management about the likely magnitude of response to changes in the hydropower corridor and the likely range of response to potential variation in environmental conditions. These kinds of estimates are critical components of planning, and we apply them to observed "gaps" between the current status of populations and ICTRT viability criteria for abundance and productivity in the accompanying report (Interior Columbia Technical Recovery Team 2007b). Because of the uncertainty associated with projecting future survival through the hydropower corridor or future environmental conditions, as well as the inherent uncertainty of all modeling exercises, the survival-related changes described here and in the accompanying report should be used as information to guide planning efforts, rather than as targets themselves. In addition, this analysis is limited to abundance and productivity, it does not address potential responses of the populations to these scenarios with respect to viability criteria for spatial structure and diversity.

## Key questions addressed

We evaluated scenarios that included alternative hydropower system survivals and alternative early ocean survival, and asked two primary conceptual questions and one methodological question:

1) *What is the effect on population status of changing survival through the FCRPS hydropower system?* In this analysis, we evaluated the effect of improving survival through the hydropower system from the baseline period (1980-2001) to survival during the current period (2001-2005 for most ESUs) and to levels estimated in the BiOp remand process using the COMPASS model (FCRPS BiOp 2007). COMPASS model estimates were used because other alternative estimates are not available for the prospective time period. All these scenarios include both directly induced mortality and any natural mortality that would occur in an unregulated river. It has been challenging to separate natural mortality during the outmigration from hydro-system induced mortality, therefore we do not attempt to separate them. Future work, aimed at comparing mortality in several large river systems (NWFSC, unpub.), may help to separate these effects. We also examined the effect of a hypothetical scenario in which we increased downstream migration survival to 100% to evaluate whether additional improvements in other sectors would be necessary regardless of the potential improvements in the hydrosystem. [This scenario is not equivalent to 100% transportation, which would include some mortality during the transportation process and differential delayed

mortality due to transportation. We did not model the 100% transportation scenario.]

2) *What is the effect on population status of alternative environmental survival regimes?* We evaluated three environmental regimes: a) one over the entire historical record for which we had data. This period (1946-2001) includes years (as assessed by PDO indices) that were both favorable and unfavorable for Snake River spring/summer Chinook salmon in about equal measure; b) a second time period uses a series of years that were largely unfavorable for Snake River spring/summer Chinook salmon (1977-1997). This time period coincides with a "warm" phase of the PDO; and c) a time period equivalent to that seen over the baseline period (1980-2001). This period is equivalent to the time periods over which the ICTRT has conducted status assessments for interior salmonid populations (ICTRT 2007a) and is used to as to calibrate results to current status. This set includes a large majority of years that were unfavorable for salmon and a few years at the end of the time period that were favorable. While the distribution of favorable and unfavorable conditions in the future is unknown, these scenarios provide data-based bounds on a plausible range of future conditions.

3) *What is the effect of evaluating productivity over different time scales?* With this question, we investigate the impact of estimating changes in productivity and abundance over relatively short and relatively longer time scales. The estimated productivity can be important in planning needed changes, so we present the

effect of running simulations for short (25 years), moderate (50 years) and relatively long (100 years) time periods.

## II. METHODS

### 1. Populations evaluated and general model structure

This modeling effort was a three-step process. First, we constructed stochastic, density-dependent matrix models for four Chinook salmon populations in two ESUs and two steelhead populations in two ESUs in the Interior Columbia (Table 1) by modifying the general structure of an ESU-level model developed by Zabel et al. (2006) for Snake River spring/summer Chinook. Second, we estimated model parameters based on available historic data. Third, we used the model in a prospective, predictive mode to address the questions posed above. We did this by varying key model inputs and observing how model outputs responded.

We were unable to model populations in the Upper Columbia steelhead ESU due to insufficient data, or in the Snake River/Redfish Lake sockeye population as this population is supported by a captive broodstock program right now. A model for the Snake River fall Chinook population is currently being developed; this ESU has shown the development of novel life history strategies, making model development more complex. Populations for which we were able to develop models are presented in Table 1.

Table 1. Populations belonging ESUs listed under the Endangered Species Act in the Interior Columbia basin in this report.

| ESU | MPG | Population | Habitat condition (from McClure et al. 2004) |
|---|---|---|---|
| Snake River spring/summer Chinook | Middle Fork Salmon River | Marsh Creek | Very good (minimal impacts) |
| | South Fork Salmon River | South Fork Salmon mainstem | Moderate (some areas with probability of significant impacts) |
| | Grande Ronde/Imnaha | Catherine Creek | Poor (substantial probability of high impacts) |
| Upper Columbia spring Chinook | East Cascades | Wenatchee | Moderate (some areas with probability of significant impacts) |
| Snake River steelhead | Salmon River | Little Salmon River | Poor (substantial probability of high impacts) |
| Mid-Columbia steelhead | Umatilla-Walla Walla | Umatilla River | Poor (substantial probability of high impacts) |

As an overview, the stochastic life-cycle model is expressed as:

$$\mathbf{n}(t + 1) = \mathbf{A}(t) \cdot \mathbf{n}(t)$$

where the vector $\mathbf{n}(t)$ represents the number of individuals at the end of time step $t$ by age (referenced to date of fertilization), and $\mathbf{A}(t)$ is an N x N stochastic population projection matrix (Caswell 2000) that varies at each time step, with its dimension determined by the longest lived individuals in the population and the details of the matrix determined by life-history patterns.

The primary data underlying our modeling were population-specific spawner counts or estimates of total spawner numbers expanded from redd counts. These adult counts, coupled with annual age structure, provide the basis for annual estimates of productivity, (spawner-to-spawner ratios), time trends in abundance, and year-to-year variability. Additional sources of data, particularly smolt-to-adult return rates (SARs) allowed us to partition these life cycle survivals into two major components: spawner-to-smolt survival, and smolt-to-adult survival. Within each of these major components, we further partitioned the survival as available data allowed. Measurement error and data uncertainty varied from population to population; specific treatment of these issues are presented in relevant sections below.

## 2. Stream-type Chinook salmon

Based on the life history of Snake River spring and summer Chinook salmon, a matrix **A**($t$) for stream-type populations in the Interior Columbia Basin takes on the form:

$$\mathrm{A}(t) = \begin{matrix} 0 & 0 & 0 & b_4 \cdot s_A \cdot F_4(t) & s_A \cdot F_5(t) \\ s_2 & 0 & 0 & 0 & 0 \\ 0 & s_3(t) & 0 & 0 & 0 \\ 0 & 0 & (1-b_3)\cdot s_o & 0 & 0 \\ 0 & 0 & 0 & (1-b_4)\cdot s_o & 0 \end{matrix}$$

Each element of the matrix, $a_{ij}$, represents the transition of $i$-year-olds (columns) to $j$-year-olds (rows) during a yearly time step. In the simplest case this is just a survival rate, such as $s_2$, which is the survival of 1-year-old fish through to the second year. The $s_3$ term represents survival during the first year in saltwater (estuarine and early ocean residence) and is determined by yearly-varying climate indices. The $b_3$ and $b_4$ terms are the propensity for adults to breed as 3- and 4-year-olds, respectively. Thus, for example, a proportion $b_4$ of the 4-year-olds spawn and then die, whereas $(1 - b_4)$ of the individuals remain in the ocean, following (Ratner et al. 1997). $s_A$ is survival from arrival of adults to Bonneville Dam to the spawning ground and incorporates survival during upstream migration through the hydrosystem ($s_u$), harvest in the river ($h_r$), and survival from the uppermost dam to the subbasin ($s_{sb}$). The $F_i$ terms describe fertility (number of one-year-olds produced per spawner, or equivalently, fecundity multiplied by first-year survival) at age i. The derivation of all these terms is described below. Stochasticity is applied in the $s_3$ and $F_i$ terms; density-dependence is applied in the fertility terms.

## *2.1 Components of spawner-to-smolt survival*

The goal of this part of the analysis was to characterize population-specific freshwater productivity by developing relationships linking the production of parr and smolts to spawner abundance. Yearly estimates of the abundance of spawners and recruits ($R_t$, returning spawners referenced to brood year) were available for each population (see (Interior Columbia Technical Recovery Team 2007a) for a description of these data), but yearly estimates of population-specific parr and smolt abundances were typically unavailable. Therefore, we followed a several step process to estimate parr recruits based on recruits of spawners as follows:

$$parr_{t+1} = R_t /(s_{sb} \cdot SAR_{t+2} \cdot s_{p-s})$$

where $s_{sb}$ is survival from the uppermost dam to the subbasin, which is deterministic (set to 0.9 as in (Marmorek et al. 1998, Kareiva et al. 2000), SAR is the smolt to adult survival, which varies yearly (described in detail below), and $s_{p\text{-}s}$ is population-specific parr to smolt survival, which is modeled deterministically.

Parr-to-smolt survival rates were derived from empirical data. For the Snake River spring/summer Chinook populations, we used a mean (across several years) population-specific parr-smolt survival rate (Levin et al. 2002) that encompassed the time and distance from mid-summer in the natal basin to Lower Granite Dam. For the Wenatchee River population, we divided estimates of smolts emigrating from the Chiwawa River (counted at a smolt trap) by estimates of parr abundance in the previous year based on parr surveys (Hillman and Miller 2002). This survival estimate encompassed the time and distance from residence as parr in the Chiwawa River to emigration as smolts the following year, a shorter time period and distance than encompassed in the Snake River spring/summer Chinook parr-to-smolt estimates. Thus, the "parr-to-smolt" stage shows fairly different mortality between the two ESUs. However, the model structure remains the same. Due to data limitations, parr-to-smolt survival was assumed to be density independent and deterministic. This had the effect of incorporating all stochasticity and density dependence into the spawner to parr stage. However, overall density dependence and associated variability in freshwater productivity was preserved.[2]

Following Zabel et al. (2006), we incorporated density-dependence in the spawner-to-parr stage by applying a Beverton-Holt relationship to relate number of one-year olds (parr) at time $t + 1$ ($n1[t+1]$) per spawner as a function of spawners:

$$\frac{n_1(t+1)}{spawner(t)} = \frac{a}{1 + b \cdot spawner(t)}$$

[2] This model structure mathematically places all the density-dependence at the spawner-parr stage. For evaluating the effects of alternative habitat actions that might affect density-dependent survival from the parr-smolt stage, an alternative model structure should be considered.

where the parameter *a* is juveniles per spawner at the origin, *b* is the density-dependent parameter, and *a*/*b* is the carrying capacity of the system. Differential fecundity of different age classes was treated as follows: Three-year olds were excluded because they were almost exclusively jacks. Because older fish are more fecund, when data were available we converted adult counts to "effective" spawners at time *t* (spawners[*t*]) by multiplying the older fish by a "fecundity factor". For Snake River spring and summer Chinook, we multiplied the number of 5-year-old fish by 1.26 to account for their approximate 26% increase in fecundity compared with 4-year-olds (Kareiva et al. 2000).

We also included stochasticity at this stage by applying a multiplicative exponential error (normally distributed) to account for the generally logarithmic distribution of the data (for a given number of spawners) and to maintain the biological interpretation of the parameters. This error structure also resulted in a better concordance with a normal distribution based on normal probability plots. Further, we used a Box-Cox transform to account for variance decreasing with increasing spawners (see Zabel et al. 2006 for details). Plots of these fits are provided in Figure 1 and parameter estimates are provided in Table 2.

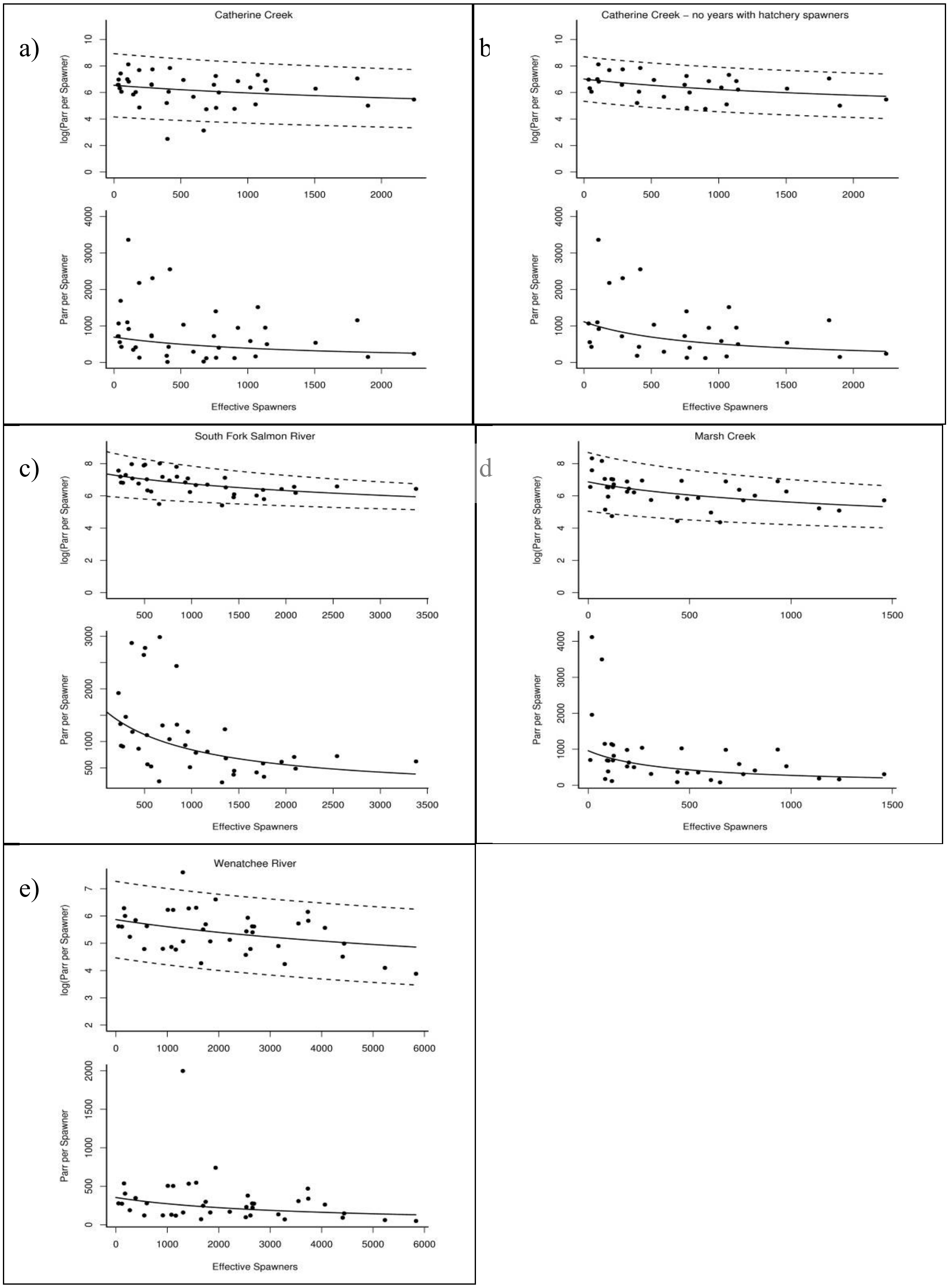


Figure 1: Estimates of parr per spawner as a function of the number of spawners, using a Beverton-Holt relationship for five populations of Chinook salmon (Snake River Spring/Summer Chinook ESU (SRSS) and Upper Columbia River Spring Chinook ESU (UCS)) in the interior Columbia River basin, with log-transformed with 95% confidence intervals (top plot in panels) and untransformed (bottom plot in panels) estimates. Corresponding panels include: a) Catherine Creek, including years with high hatchery contributions (SRSS); b) Catherine Creek, excluding years with high hatchery years (SRSS); c) South Fork Salmon River (SRSS); d) Marsh Creek (SRSS); and e) Wenatchee River (UCS).

### *2.1.1 Catherine Creek – accounting for population-specific uncertainty*

The Catherine Creek population experienced a period of high fraction of hatchery spawners during the 1990s and freshwater productivity (expressed as parr-per-spawner) appeared lower during this period. Because we were unable to determine whether this was real, or a transient artifact, we analyzed the Catherine Creek data set both with and without the years with high hatchery fraction to provide bounds on the potential response of this population to alternate scenarios. The high hatchery fraction years eliminated in the alternative analysis correspond to years with relatively low return rates for other Snake River spring-summer Chinook populations. In addition, direct estimates of smolts per redd and survival of smolts from Catherine Creek to Lower Granite Dam have shown substantial declines in recent years, including production from parent escapements with low hatchery contributions. As a result, the geometric mean productivity estimates for this series may be biased upward in comparison with current performance and should be interpreted with caution.

## *2.2 Components of Smolt-to-Adult Survival*

We broke smolt-to-adult survival into five components: juvenile system survival through the hydrosystem; estuarine and early ocean survival; adult ocean survival; upstream migration survival rate ($s_u$); and in-river harvest. Spring/summer Chinook smolts in a migration year are nearly all from the same brood year, therefore we used the age-specific term $s_3$ to represent first year estuary/ocean survival (Table 2). To estimate this parameter ($s_3$), we factored the other components out of the total smolt-to-adult survival as described below.

### *2.2.1 Smolt to adult survival (SAR)*

Chinook salmon smolt to adult survival rates were derived from several sources. For Snake River spring and summer Chinook salmon, we used previously published estimates of smolt to adult survival (Petrosky et al. 2001, Williams et al. 2005, Berggren et al. 2006). These were based on the number of smolts at the uppermost dam (Lower Granite since 1975) and adult returns to the upper dam plus harvest in the mainstem Columbia River.

Table 2. Parameters used in Leslie matrix models for Marsh Creek, Catherine Creek, South Fork Salmon River, and Wenatchee River populations.

| | Marsh Creek | Catherine Creek | South Fork Salmon River | Wenatchee River |
|---|---|---|---|---|
| Beverton-Holt "a" | 958.025 | 693.630 (1113.485) | 1723.179 | 353.437 |
| Beverton-Holt "b" | 0.00251 | 0.000783 (0.00120) | 0.00104 | 0.000298 |
| $\sigma^2_1$ | 0.00552 | 0.218 (0.705) | $1.82 \times 10^{-5}$ | 0.412 |
| $\phi$ (variance term) | 2.6 | 1.0 (0.0) | 5.1 | 0.1 |
| Parr-smolt survival[1] | 0.161 | 0.164 | 0.114 | 0.6 |
| Hydrosystem survival | Dependent upon scenario run (see Table 5) | Dependent upon scenario run (see Table 5) | Dependent upon scenario run (see Table 5) | Dependent upon scenario run (see Table 5) |
| $S_3$ | Stochastic variable, dependent on relationship to ocean conditions | Stochastic variable, dependent on relationship to ocean conditions | Stochastic variable, dependent on relationship to ocean conditions | Stochastic variable, dependent on relationship to ocean conditions |
| Adult ocean survival | 0.8 | 0.8 | 0.8 | 0.8 |
| Propensity to breed (3 year olds) | 0.0345 | 0.0345 | 0.0345 | 0.046 |
| Propensity to breed (4 year olds) | 0.4592 | 0.4592 | 0.4592 | 0.514 |
| Fecundity factor | 1.26 | 1.26 | 1.26 | 1.00 |
| Harvest rate | 0.07 | 0.07 | 0.07 | 0.09 |
| Bonneville-to-basin survival rate | 0.806 | 0.806 | 0.806 | 0.794 |
| Pre-spawning survival rate | 0.9 | 0.9 | 0.9 | 0.9 |
| Initial abundance | 75 | 67 | 695 | 781 |

[1] Note that parr-smolt survival for the Snake River spring/summer Chinook populations measures survival from summer parr, overwintering to the top of Lower Granite Dam. Parr-smolt survival for the Wenatchee River population measures survival from exiting the tributaries until reaching the mainstem Columbia.

For Wenatchee River spring Chinook, we developed SAR estimates from two sources. First, SAR estimates for naturally produced spring Chinook originating from the Chiwawa, are available for outmigration years 1992 to 2003. In addition, SAR estimates for annual spring Chinook releases from Leavenworth Hatchery (located on Icicle Creek in the lower Wenatchee drainage) are available for migration years 1982 to 2002 (David Carie, USFWS, unpub. data). The two series were highly correlated (correlation coefficient = 0.80), although the Leavenworth Hatchery SARs were consistently lower than the corresponding Chiwawa wild estimates. We regressed the Chiwawa wild SARs on the Leavenworth Hatchery series, and extended the wild SAR series back to the 1982 migration year using this regression. We assumed that the resulting series of smolt-to-adult survival rates applied to the aggregate natural production from the Wenatchee population.

### *2.2.2 Literature-derived values: Harvest Rates and Adult Ocean Survival*

We assumed that adult ocean survival $s_o = 0.8$ (Ricker 1976) and applied it for each of the years spent in the ocean. This assumption is consistent with previous cohort-based Chinook modeling studies (Pacific Salmon Commission Chinook Technical Committee reports, and (Petrosky et al. 2001). In-river harvest rates were derived from (Petrosky et al. 2001, Williams et al. 2005) and Technical Advisory Committee estimates.

*2.2.3 Juvenile migration survival*

Juvenile survival through the hydrosystem consists of several sub-components: in-river survival rate, proportion of fish transported, survival of transported fish, and differential delayed mortality associated with transportation or 'D.' Total system survival is as follows:

$$s_d(t) = p_T\,(t) \cdot s_T(t) + (1 - p_T\,(t)) \cdot s_I\,(t)$$

where $s_d(t)$ is survival of downstream migrants through the hydrosystem, $p_T\,(t)$ is the portion of fish arriving at the uppermost dam that were transported (Marmorek et al. 1998; Williams et al. 2005), $s_T(t)$ is the survival of transported fish, and $s_I\,(t)$ is the survival of in-river migrants.

For Snake River population, in-river juvenile hydrosystem survival and proportion of transported fish were taken from (Williams et al. 2001, Williams et al. 2005, Berggren et al. 2006). Downstream survival estimates for wild smolts were lacking for 1981–1992, so we omitted this time period from analyses. The $s_T$ parameter includes a "delayed differential mortality" (D) of transported fish (from Williams et al. 2005, Berggren et al. 2006), accounting for the fact that transported fish return at lower rates than fish that migrated volitionally. Although this delayed mortality is most likely expressed during the early ocean life stage, we applied it to the downstream migration stage because it simplifies calculation of the early ocean survival term and is mathematically equivalent. We used PIT-tag derived estimates of D for 1994-2001 (Berggren et al. 2006). The geometric mean of D-values was 0.47 (range 0.32 to 0.86), excluding the major drought year of 2001 when D equaled 2.20. For the pre-1993 migration years we reconstructed hydrosystem survival by sampling from the distribution of D for all years except for major drought years (1973 and 1977) where we assumed the 2001 estimate applied.

Upper Columbia spring Chinook salmon are not transported. We used in-river survival rates from Williams et al. 2005 for the mainstem Columbia and PUD studies (Grant PUD 2003, Skalski et al. 2005) for survival through hydroelectric projects above the confluence with the Snake River.

*2.2.4 Adult upstream migration survival*

For Snake River spring/summer Chinook, we estimated upstream migration survival from two sources. PIT-tag estimates of survival to Lower Granite Dam (Williams et al. 2005, Clugston 2006) are available for 1999-2003, and average 0.88 (range 0.84 to 0.92). A longer time series of $s_u$ estimates based on dam counts was available in the US v. Oregon Technical Advisory Committee run reconstruction of upriver spring and summer Chinook adult returns for return years 1965-2004 (E. Tinus, ODFW and H. Yuen, USFWS). However, these estimates averaged 0.66 over the same time period as the PIT-tag estimates. We believe that the $s_u$ values estimated from the more recent PIT-tag studies are most accurate but are for a limited time period after adult passage improvements were implemented (spill pattern management, attraction flows). Therefore, we assumed the run reconstruction $s_u$ estimates captured the temporal pattern of the time series and adjusted the run reconstruction $s_u$ by the ratio between the two methods (Table 3).

Table 3. Adjustments to estimates of adult upstream migration survival using recent PIT-tag survival estimates.

| | Upstream survival - run | | | | | Upstream survival - PIT | | |
|---|---|---|---|---|---|---|---|---|
| Return year | Snake Basin spring run | Snake Basin spring/ summer | Snake Basin summer run | Wild PIT upstream LGR/BON detections | Wild PIT upstream survival spring/ summer | spring | spring/ summer | summer |
| 1949 | 1 | 1 | 1 | | | 1 | 1 | 1 |
| 1950 | 1 | 1 | 1 | | | 1 | 1 | 1 |
| 1951 | 1 | 1 | 1 | | | 1 | 1 | 1 |
| 1952 | 1 | 1 | 1 | | | 1 | 1 | 1 |
| 1953 | 1 | 1 | 1 | | | 1 | 1 | 1 |
| 1954 | 0.57 | 0.67 | 0.78 | | | 0.76 | 0.88 | 1 |
| 1955 | 0.4 | 0.67 | 0.94 | | | 0.54 | 0.89 | 1 |
| 1956 | 0.26 | 0.62 | 0.98 | | | 0.35 | 0.82 | 1 |
| 1957 | 0.79 | 0.85 | 0.91 | | | 1 | 1 | 1 |
| 1958 | 0.82 | 0.79 | 0.76 | | | 1 | 1 | 0.98 |
| 1959 | 0.71 | 0.78 | 0.85 | | | 0.96 | 1 | 1 |
| 1960 | 0.82 | 0.86 | 0.91 | | | 1 | 1 | 1 |
| 1961 | 0.75 | 0.72 | 0.68 | | | 1 | 0.95 | 0.88 |
| 1962 | 0.58 | 0.61 | 0.63 | | | 0.79 | 0.8 | 0.81 |
| 1963 | 0.61 | 0.62 | 0.62 | | | 0.83 | 0.81 | 0.8 |
| 1964 | 0.55 | 0.59 | 0.63 | | | 0.74 | 0.77 | 0.8 |
| 1965 | 0.33 | 0.43 | 0.53 | | | 0.45 | 0.57 | 0.68 |
| 1966 | 0.64 | 0.63 | 0.63 | | | 0.87 | 0.84 | 0.81 |
| 1967 | 0.76 | 0.68 | 0.6 | | | 1 | 0.9 | 0.77 |
| 1968 | 0.81 | 0.73 | 0.64 | | | 1 | 0.96 | 0.82 |
| 1969 | 0.47 | 0.49 | 0.51 | | | 0.64 | 0.65 | 0.65 |
| 1970 | 0.62 | 0.64 | 0.66 | | | 0.84 | 0.85 | 0.85 |
| 1971 | 0.36 | 0.49 | 0.61 | | | 0.49 | 0.64 | 0.78 |
| 1972 | 0.39 | 0.45 | 0.51 | | | 0.53 | 0.6 | 0.65 |
| 1973 | 0.71 | 0.65 | 0.58 | | | 0.96 | 0.85 | 0.75 |
| 1974 | 0.48 | 0.53 | 0.57 | | | 0.65 | 0.69 | 0.74 |
| 1975 | 0.29 | 0.49 | 0.69 | | | 0.4 | 0.65 | 0.89 |
| 1976 | 0.51 | 0.6 | 0.69 | | | 0.7 | 0.79 | 0.89 |
| 1977 | 0.69 | 0.65 | 0.61 | | | 0.93 | 0.85 | 0.78 |
| 1978 | 0.53 | 0.64 | 0.75 | | | 0.72 | 0.85 | 0.97 |
| 1979 | 0.4 | 0.56 | 0.73 | | | 0.54 | 0.74 | 0.93 |
| 1980 | 0.35 | 0.49 | 0.63 | | | 0.47 | 0.65 | 0.81 |
| 1981 | 0.59 | 0.57 | 0.55 | | | 0.8 | 0.75 | 0.71 |
| 1982 | 0.43 | 0.5 | 0.57 | | | 0.58 | 0.66 | 0.73 |
| 1983 | 0.52 | 0.56 | 0.59 | | | 0.71 | 0.74 | 0.76 |
| 1984 | 0.57 | 0.66 | 0.76 | | | 0.77 | 0.88 | 0.97 |
| 1985 | 0.73 | 0.76 | 0.78 | | | 0.99 | 1 | 1 |
| 1986 | 0.63 | 0.71 | 0.79 | | | 0.85 | 0.94 | 1 |
| 1987 | 0.75 | 0.65 | 0.56 | | | 1 | 0.86 | 0.73 |
| 1988 | 0.7 | 0.61 | 0.51 | | | 0.95 | 0.8 | 0.66 |
| 1989 | 0.52 | 0.61 | 0.69 | | | 0.7 | 0.8 | 0.89 |
| 1990 | 0.68 | 0.69 | 0.7 | | | 0.91 | 0.91 | 0.9 |
| 1991 | 0.48 | 0.59 | 0.69 | | | 0.65 | 0.77 | 0.88 |
| 1992 | 0.74 | 0.65 | 0.56 | | | 1 | 0.86 | 0.72 |
| 1993 | 0.73 | 0.8 | 0.88 | | | 0.99 | 1 | 1 |
| 1994 | 0.73 | 0.68 | 0.62 | | | 0.99 | 0.89 | 0.8 |
| 1995 | 0.47 | 0.54 | 0.61 | | | 0.63 | 0.71 | 0.78 |
| 1996 | 0.39 | 0.57 | 0.76 | | | 0.53 | 0.76 | 0.97 |
| 1997 | 0.51 | 0.63 | 0.76 | | | 0.68 | 0.83 | 0.97 |
| 1998 | 0.53 | 0.56 | 0.6 | | | 0.71 | 0.74 | 0.77 |
| 1999 | 0.38 | 0.53 | 0.68 | 0.889 | 0.916 | 0.51 | 0.69 | 0.87 |
| 2000 | 0.55 | 0.58 | 0.61 | 0.819 | 0.846 | 0.75 | 0.77 | 0.78 |
| 2001 | 0.89 | 0.8 | 0.72 | 0.774 | 0.84 | 1 | 1 | 0.93 |
| 2002 | 0.73 | 0.73 | 0.73 | 0.838 | 0.91 | 0.99 | 0.96 | 0.94 |
| 2003 | 0.69 | 0.68 | 0.67 | 0.815 | 0.909 | 0.93 | 0.9 | 0.87 |
| 2004 | | | | 0.86 | 0.919 | | | |
| 2005 | | | | 0.848 | 0.906 | | | |

Adult upstream migration survival for Upper Columbia spring Chinook salmon was assumed to be equal to 0.794, following estimates in Zabel et al (2006) for Snake River stream-type Chinook.

*2.2.5 Estuarine and early ocean survival* -- $s_3$

With the other components of smolt-to-adult return rates estimated, we back-calculated third-year survival ($s_3(t)$) estimates from SAR data while taking into account year-to-year variability in hydrosystem survival, harvest, and age composition of returning adults. Specifically, we based this value on smolt counts at year *t* and age-specific adult counts at years $t$+1, $t$+2, and $t$+3 at the uppermost dam. We note that:

$$s_3(t) = n_3(t+1)/n_2(t),$$

where $n_i(t)$ is the number of individuals of age *i* at time *t*. The $n_2(t)$ term is derived from the number of smolts as follows:

$$n_2(t) = s_d(t) \cdot \text{smolts}(t),$$

We back-calculated $n_3(t+1)$ from the number of adults returning as 3-year-olds in $t + 1$ (designated $n_{A3}[t + 1]$), the number of 4-year-olds returning in $t + 2$ (designated $n_{A4}[t + 2]$), and the number or 5-year-olds returning in $t + 3$ (designated $n_{A5}[t + 3]$). These counts were then adjusted to account for mortality occurring during upstream migration, harvest rate in the river, and ocean survival. In this manner, we estimated $n3(t + 1)$ as:

$$n_3(t+1) = 1/su \cdot \{( n_{A3}(t+1))/(1-hr\,(t+1)\,) + (n_{A4}(t+2))/(so \cdot [1-hr\,(t+2)])$$

$$+ (n_{A5}(t+3))/(s_o^{2} \cdot [1 - hr\,(t+3)])\}$$

We used these estimates of $n_3$ and $n_2$ to estimate annual $s_3$ values. This term implicitly includes any latent mortality attributable to the hydropower system.

*2.2.6 Simulating estuarine and early ocean survival*

The estuarine and early ocean life stage is linked to freshwater and marine condition indicators and is stochastic in this model. We first developed a relationship between the observed indicators (referred to as environmental indicators in this paper) and the estuarine-early ocean survival rates we estimated above. We then used this relationship, and the variability around it to simulate alternative environmental scenarios.

We explored a number of potential climate indicators for predicting annual third year survival: monthly PDO (Mantua et al. 1997), monthly upwelling, and water travel time (WTT). The first two of these variables (PDO and upwelling) are indicators of ocean conditions. We selected candidate monthly indices (April, May, June, September and October) for potential inclusion in the model based on previous studies (Scheuerell and Williams 2005, Zabel et al. 2006). The third variable (WTT), is a measure of the average time it takes for water particle to move through a river reach during a specified time period, and was used as an indicator of overall freshwater and in-river conditions. It is derived in part from flow measurements and is tightly correlated with total Columbia flow for a given reservoir volume (Figure 2). We calculated WTT for the spring smolt migration period (April 16 – May 31) from the first mainstem reservoir encountered to Bonneville Dam. We also evaluated a model using a first-order autocorrelation function rather than specific predictors. In this model, we assumed that $s_3(t+1)$ was correlated to $s_3(t)$

We used stepwise multiple regression (based on AIC values) to select among alternate models (Appendix A). The models selected (Figure 3) were:

Snake River spring/summer Chinook:

$$s_3 = -1.21 -0.101 (WTT_{Snake})+0.0185(Upwelling_{Apr})-0.313(PDO_{Sep})$$

Upper Columbia spring Chinook:

$$s_3 = -1.31 -0.177 (WTT_{Wen})+0.0363(Upwelling_{Apr})-0.0114(Upwelling_{May})$$

We used these relationships, with their associated variability to simulate $s_3$, using input predictors associated with different conditions (i.e. Baseline, Warm PDO, Historical).

In addition to alternate predictors, we tested the effect of using subsets of years as a response variable in order to evaluate the possibility that the relationship between climate indicators and early ocean survival was different in different time periods, but found no significant change between time periods (Appendix B). We thus carried this analysis no further.

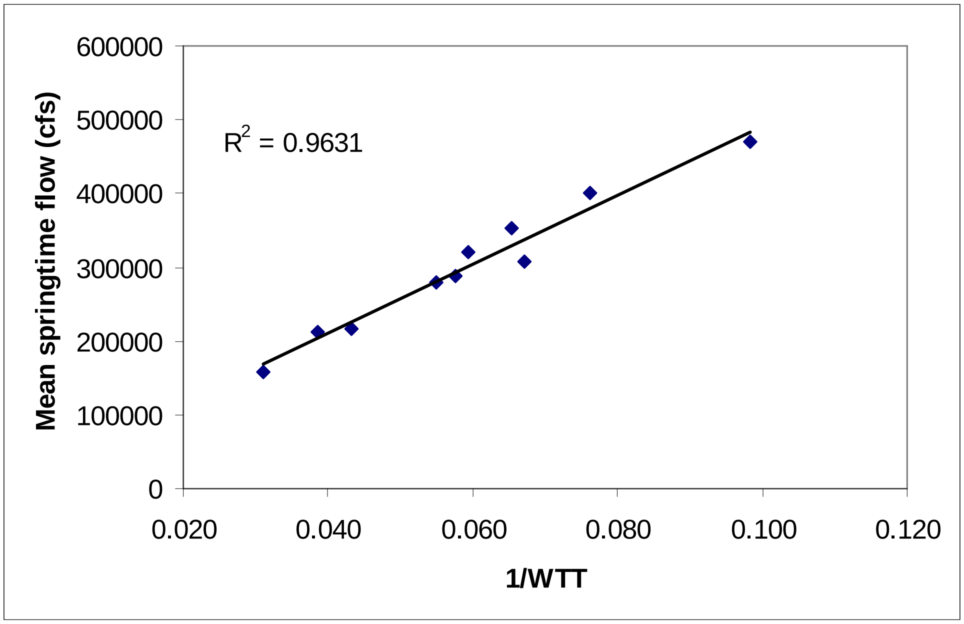


Figure 2: The relationship between water travel time (WTT, days) and mean springtime flow (cfs) in the Columbia River, as measured at Bonneville Dam.

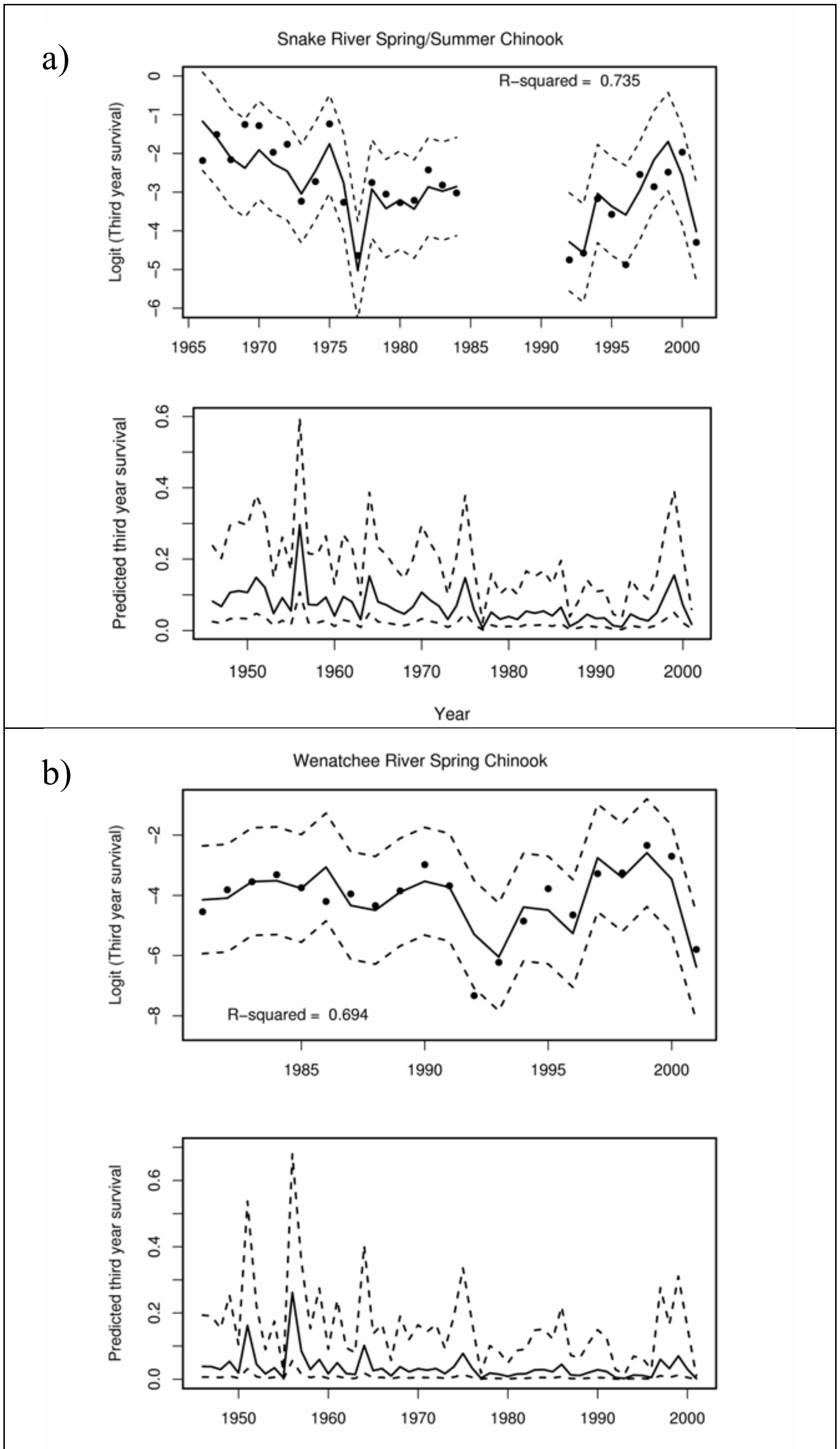

Figure 3: Model fits (top, with 95% confidence intervals) and predictions of third year survival (bottom, with 95% prediction intervals) of a) Snake River Spring/Summer Chinook, and b) Wenatchee River (Upper Columbia River Spring Chinook), as estimated by a combination of environmental variables and water travel time.

## 3. Steelhead

Steelhead have a more complex life history than stream-type Chinook salmon, exhibiting multiple smolt ages and a freshwater overwintering period prior to spawning. Accordingly, the matrix for steelhead covers three distinct life stages: freshwater juveniles (ages 1-4), ocean, and freshwater overwintering of adults. Spawning occurs in springtime, so the age classes are delineated from spring to spring. Age classes are enumerated at the end of a year. Thus, for example, one-year olds are enumerated at spring, a year after fertilization. The model is structured as follows:

Year t

| Year t+1 | fw1 | fw2 | fw3 | fw4 | O1 | O2 | OW |
|---|---|---|---|---|---|---|---|
| fw1 | | | | | | | F |
| fw2 | $s_{fw2}$ | | | | | | |
| fw3 | | $(1-sm_2)\bullet s_{fw3}$ | | | | | |
| fw4 | | | $(1-sm_3)\bullet s_{fw4}$ | | | | |
| O1 | | $sm_2\bullet s_d\bullet s_{O1}$ | $sm_3\bullet s_d\bullet s_{O1}$ | $s_d\bullet s_{O1}$ | | | |
| O2 | | | | | $(1-b_1)\bullet s_{O2}$ | | |
| OW | | | | | $b_1\bullet s_A\bullet s_{OW}$ | $s_A\bullet s_{OW}$ | |

Where:
$s_{fw2}$, $s_{fw3}$, $s_{fw4}$ = survival during 2nd, 3rd, and 4th years in freshwater
$sm_i$ = propensity to smolt at age i
$s_d$ = downstream migration survival
$s_A$ = upstream migration survival, including harvest
$s_{O1}$, $s_{O2}$ = survival in ocean during 1st and 2nd years
$s_{ow}$ = survival during adult overwintering
$b_1$ = propensity to breed as 1-ocean fish
F = fertility (does not vary by ocean age due to lack of data)

Parameters used are shown in Table 4.

Table 4. Parameters used in Leslie matrix models for the Little Salmon River and Umatilla River steelhead populations.

| Parameter | Little Salmon River (Rapid River) | Umatilla River |
|---|---|---|
| Beverton-Holt "a" | 200 | 200 |
| Beverton-Holt "b" | 0.06254 | 0.00402 |
| $\sigma^2_1$ | 0.307 | 0.0165 |
| $\phi$ (variance term) | 0.0 | 2.0 |
| Freshwater survival year 2 ($s_{fw2}$) | 1.0 | 1.0 |
| Freshwater survival year 3 ($s_{fw3}$) | 1.0 | 1.0 |
| Freshwater survival year 4 ($s_{fw4}$) | 1.0 | 1.0 |
| Propensity to smolt at age 2 ($sm_2$) | 0.0 | 0.908 |
| Propensity to smolt at age 3 ($sm_3$) | 0.6 | 1.0 |
| Juvenile hydrosystem survival | Dependent upon scenario run (see Table 5) | Dependent upon scenario run (see Table 5) |
| Estuarine and early ocean survival $S_{eo}$ | Stochastic variable, dependent on relationship to environmental conditions | Stochastic variable, dependent on relationship to environmental conditions |
| Adult ocean survival ($s_{02}$) | 0.8 | 0.8 |
| Propensity to breed as 1-ocean fish ($b_1$) | 0.412 | 0.570 |
| Harvest rate | 0.07 | 0.031 |
| Bonneville-to-basin survival rate ($s_{up}$) | 0.77 | 0.907 |
| Overwinter survival rate | 0.9 | 0.9 |
| Initial abundance | 99.2 | 3416 |

*3.1 Components of spawner to smolt survival*

Steelhead freshwater life history patterns are more complex than those of stream-type Chinook and few data exist to estimate demographic rates, such as yearly survival, during the freshwater life stages. Thus, we simplified the juvenile component of the steelhead model to reflect the data available – counts and ages of outmigrating smolts. Accordingly, we assumed that yearly survival during juvenile rearing ($s_{\mathrm{fw2}}$, $s_{\mathrm{fw2}}$, and $s_{\mathrm{fw2}}$) was equal to 1.0, and consequently the Fertility term, *F*, related smolts production as a function of spawner abundance. In addition, we set the propensity to smolt terms ($sm_2$ and $sm_3$) to produce the observed age distribution of smolts. These simplifications did not alter the overall smolt production relationships and associated variability. However, acquiring additional empirical data on steelhead stage specific survival rates would be extremely useful for future modeling exercises are directed at steelhead, particularly those addressing potential freshwater survival improvements during specific life stages.

For Snake River steelhead, we estimated smolt abundances as we did for Chinook salmon parr by back calculating smolts from adult recruits and SARs corresponding to brood years 1978-1996. This required the additional step of assigning smolts to brood year according to smolt age distributions. For Umatilla River steelhead, estimates of spawners and smolts were obtained directly from counts at Three Mile Dam in the lower Umatilla River (pers. comm.. R. Carmichael, ODFW) corresponding to brood years 1993-2004. After we obtained estimates of spawners and smolts, we developed a Beverton-Holt relationship and associated variability for steelhead smolts as we did for Chinook salmon parr (Figure 4).

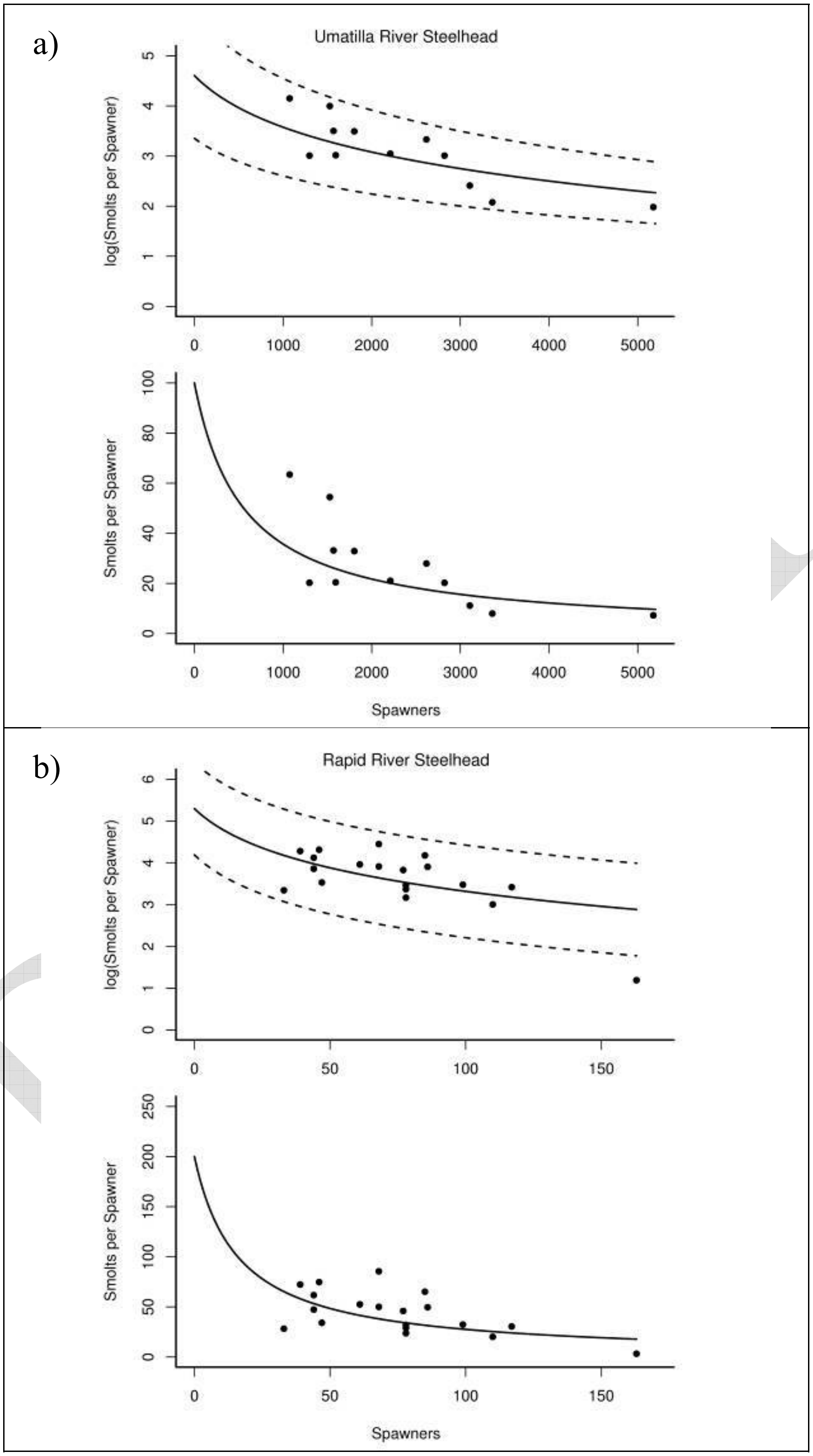


Figure 4: Estimates of smolts per spawner as a function of the number of spawners, using a Beverton-Holt relationship for two populations of steelhead (Snake River steelhead ESU) in the Interior Columbia River Basin, with log-transformed with 95% confidence intervals (top plots in panels) and untransformed (bottom plots in panels) estimates. Corresponding panels include: a) Umatilla and, b) Rapid Rivers.

### *3.2 Components of smolt-to-adult survival*

Smolt-to-adult survival in steelhead consists of juvenile outmigration survival, estuarine and early ocean survival, adult ocean survival, adult upstream migration survival, and in-river harvest. Unlike stream-type Chinook salmon, which produce predominantly yearling smolts, steelhead smolts in a given migration are from multiple brood years. Therefore, we use the more-general term $s_{O1}$, rather than $s_3$ to represent first year estuary/ocean survival. As with stream-type Chinook, we factored out known terms to estimate this parameter, and it implicitly includes any latent mortality attributable to the hydropower system.

Smolt-to-adult returns (SARs) for Snake River steelhead represented smolts at the uppermost dam (Lower Granite since 1975) and adult returns to the upper dam plus harvest in the mainstem Columbia River (Marmorek et al. 1998, Williams et al. 2005). For the Umatilla steelhead data set (Mid-Columbia steelhead ESU), SARs were derived from annual estimates of smolt outmigrants and adult returns based on sampling at Three Mile Dam in the lower Umatilla River (pers. comm.. R. Carmichael, ODFW). Estimates of the number of natural origin smolt outmigrants are available for the 1995 to present outmigration years. Annual adult return estimates (broken out by hatchery and natural origin) are available for 1977 to the present. We used the fitted Beverton Holt smolt production relationship (from the previous section) along with estimates of spawner abundances to generate annual smolt production estimates for the brood years 1977 to 1993. We allocated the resulting brood year smolt production estimates to migration year by applying the average proportions migrating at age 2 and age 3 derived from the 1995 to 2005 smolt sampling program (0.91 age 2, 0.09 age 3).

### *3.2.1 Literature-derived parameters: adult ocean survival and in-river harvest rates*

Again, several of these components we derived from the literature. Since there are no steelhead values for adult ocean survival, we assumed that survival during the second year in the ocean $s_{o2} = 0.8$ (Ricker 1976). In-river harvest rates were derived from (Marmorek et al. 1998, Williams et al. 2005) and TAC estimates.

### *3.2.2 Juvenile migration survival*

Juvenile survival associated with passage through the hydrosystem consists of several sub-components: in-river survival rate, proportion of fish transported, survival of transported fish, and differential delayed mortality associated with transportation or 'D.' Total hydrosystem survival is as follows:

$$s_d(t) = p_T(t) \cdot s_T(t) + (1 - p_T(t)) \cdot s_I(t)$$

where $s_d(t)$ is survival of downstream migrants through the hydrosystem, $p_T(t)$ is the portion of fish arriving at the uppermost dam that were transported (Marmorek et al. 1998; Williams et al. 2005), $s_T(t)$ is the survival of transported fish, and $s_I(t)$ is the survival of in-river migrants.

For Snake River steelhead, in-river survival components were taken from Williams et al. (2001) and Williams et al. (2005). The proportion of transported fish were obtained from Williams et al. (2005) for migration years 1993-2005 and from Fish Transportation Oversight Team (FTOT) reports for migration years 1985-1992 (Ceballos et al. 1993).

Wild and hatchery steelhead were not counted separately at mainstem dams before 1985. Therefore, annual estimates of total steelhead (wild plus hatchery) transport proportions were from FTOT reports for migration years 1981-1984 and (Park 1985) for migration years 1971-1979. Transported smolts were in Lower Granite equivalents, which required expanding the numbers transported from dams below Lower Granite by the in-river survival between Lower Granite and the transport site. We used a fixed D-value from the Comparative Survival Study (CSS) for 1997-2003 (Berggren et al. 2006) (geometric mean D value = 0.78 (range 0.11 to 2.27)) (See Appendix C). Fixed values were applied to all years because of wide confidence intervals on the annual estimates and large inter-annual variation.

Direct estimates of passage survivals of outmigrating steelhead smolts produced in the Umatilla River through the FCRPS projects are not available. We extrapolated estimates from the Snake River steelhead SAR series described above, based on the general assumption that annual survival rates at all FCRPS dams are similar. Umatilla River fish enter the Columbia mainstem above 3 of the FCRPS dams. Snake River steelhead migrate through a total of 8 mainstem dams, including the same three lower Columbia mainstem projects. For outmigration years after 1980, we calculated FCRPS passage survival rates for application to the Umatilla by raising the total (Lower Granite to Bonneville) in-river survival estimates for Snake River steelhead (Williams et al. 2005) to the 3/8 power. The application of these estimates to the Umatilla should be interpreted with caution. A recent study has indicated substantial and variable annual mortalities of Umatilla outmigrants in the reach including the lower Umatilla River - Three Mile Falls Dam to John Day Dam (White et al. 2007). Annual variation in survival through this reach may reflect influence of habitat degradation, primarily flow and temperature impairments in the Umatilla basin. Moreover, annual estimates of survivals through this reach are not available for the years used in reconstructing the Umatilla SAR series. Temporal variation in survival through this reach could mask or bias annual estimates of estuary/early ocean survival for this stock and therefore compromise the ability to identify influences of ocean conditions. In addition, survivals associated with the migration from natal rearing areas within the Umatilla River drainage to Three Mile Dam also exhibited substantial variation across years (White et al. 2007).

### *3.2.3 Adult upstream migration survival*

For Snake River steelhead, we used the most recent compilation of PIT tag detections from the BiOp Remand process. Upstream passage survival estimates from Bonneville Dam to Lower Granite Dam from PIT-tagged Snake River steelhead averaged 0.77 (range 0.68 to 0.82) for 2000-2005. The proportion of Bonneville Dam PIT tags detected at Lower Granite each year was adjusted by the Zone 6 harvest rate. The average $s_u$ value was assumed for the pre-2000 return years because no long-term run reconstruction estimates of $s_u$ were available for steelhead.

We estimated Mid-Columbia (Umatilla River) steelhead upstream migration survival estimates by raising upstream survival of Snake River steelhead to the 3/8$^{th}$ power to reflect that they passed 3 dams.

*3.2.4 Estuarine and early ocean survival*

With other values in the smolt-to-adult life period estimated, we back-calculated first-year estuary/ocean survival (($s_{O1}(t)$) estimates from SAR data while taking into account year-to-variability in hydrosystem survival, harvest, and age composition of returning adults, as we did with Chinook salmon populations.

*3.2.5 Simulating estuarine and early ocean survival*

As with Chinook salmon, estuarine and early ocean survival ($s_{O1}$) is stochastic in this model. We developed a relationship between estimated $s_{O1}$ and freshwater and marine environmental indicators for each population as we did for Chinook salmon, using stepwise multiple regression and selecting among models based on AIC. For the Little Salmon River population (Snake River steelhead), the model was developed from SARs for the aggregate ESU.

Models selected (Figure 5) were as follows:

Rapid River/Little Salmon River Steelhead (SR Steelhead ESU):

$$S_{O1} = -0.985 - 0.0405\,(WTT_{Snake}) + 0.664(PDO_{Apr}) - 0.939(PDO_{May}) - 0.0149(Upwell_{Sep})$$

Umatilla River (Mid-Columbia Steelhead ESU):

$$S_{O1} = -2.42 + 1.26\,(PDO_{Apr}) - 1.66(PDO_{May}) + 0.445(PDO_{June})$$

We used these regression models, and their associated variability to simulate estuarine and early ocean survival under each environmental scenario.

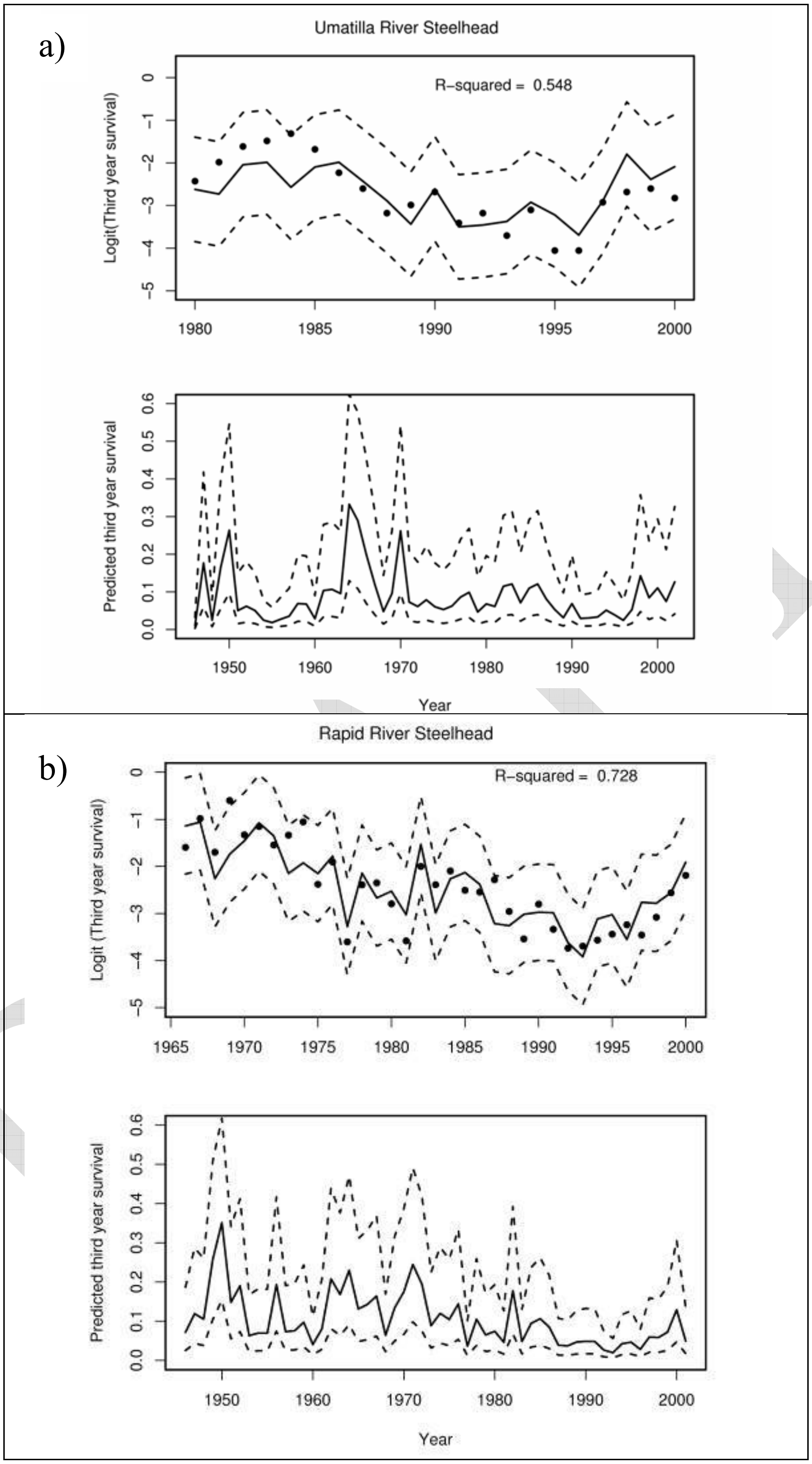


Figure 5: Model fits (top, with 95% confidence intervals) and predictions of third year survival (bottom, with 95% prediction intervals) of a) Umatilla River steelhead, and b) Rapid River steelhead, as estimated by a combination of environmental variables and water travel time.

4. Modeled Scenarios -- Anticipated survival rates in the hydropower corridor.

We modeled several deterministic scenarios of hydro-related mortality and survival to bound the range of likely survival rates through the hydropower corridor (Table 5). Each of these scenarios except the last includes both natural mortality that would occur in the absence of the hydropower system and mortality directly attributable to the hydropower system.

1) We modeled the average hydropower parameters observed through the time period on which we based our current status assessments (IC-TRT 2007b). This scenario allowed us to calibrate the proportional change in life-cycle survival rates under other scenarios to this “ baseline” survival. The term Baseline is used only for ease of comparison with ongoing FCRPS BiOp discussions, and does not imply that these are average or normal conditions.

2) We used the mean survival rates estimated for the most recent 5 years. For Snake River spring/summer Chinook, Mid-Columbia steelhead and Snake River steelhead populations, we used estimates of survival based on PIT-tag data (Williams et al. 2005). For those ESUs that are subject to transportation of juveniles, we also used the mean proportion transported and the differential delayed mortality rate of those fish (D) as estimated from PIT-tag returns. Current survival rates for hydropower projects in the Upper Columbia (operated by the Mid-Columbia Public Utility

Districts) were obtained from (Skalski et al. 2005) and (Grant PUD 2003). These estimates formed the basis of our "Current Operations" scenario for hydropower survival and allowed us to evaluate the likely proportional change that may be obtained as a result of continuing current hydropower operations for a longer period of time (and thus, to compare these with the "baseline" survival rates.)

3) To evaluate the likely effects of additional anticipated improvements in the hydrosystem, we applied the proportional change in hydrosystem survival predicted by the Compass model when comparing current operations to operations considered in the new BiOp (COMPASS 2007).

For these prospective modeling runs, we used COMPASS results produced in May 2007 for the FCRPS Biological Opinion (COMPASS 2007), which is under development. These results used the "NWFSC" reservoir survival hypothesis; other reservoir survival produced similar changes in direct survival through the hydrosystem. These results will likely change in the future (due to changes in proposed actions and modeling updates), but they represent a realistic estimate of future changes in hydrosystem survival. In addition, the prospective COMPASS results incorporated changes (compared to current conditions) in adult return rates due to changes in arrival timing resulting from changes in management actions. In particular, higher spill levels resulted in earlier arrival timing. We believe that it is appropriate to incorporate this effect in addition to the relationship between third-year survival and water travel time because it is the result of changes in operations and not changes in water travel times, which don't change between current and future operations. In addition, we did not incorporate changes in return rates between the base and current periods because we did not have sufficient data to model changes in arrival timing between these two periods.

We applied this change in survival to the current operations scenario, and this served as our "Projected BiOp" scenario. We were unable to model any variation around these projections as the Compass model is not currently producing stochastic results. Alternative analyses relating hydropower system actions to life stage survivals are being developed (e.g., ISAB 2007), and these could also be accommodated in this framework.

4) We evaluated the population response to 100% survival during the juvenile outmigration ("100% Survival"). In this scenario, we removed the direct in-river and transportation mortality (i.e. set $s_d = 1.00$ and $p_T = 0$), but did not alter any latent mortality attributable to the hydrosystem in the estuarine/early ocean life stage. This is an unrealistic scenario; even before any hydropower development in the Columbia Basin there was certainly some mortality at this life stage, although it is difficult or impossible to determine how much. Applying this scenario allowed us to place an endpoint on the range of survivals evaluated and to evaluate whether additional improvements realized outside the hydropower corridor, such as habitat restoration or improvements in fish condition or timing through the hydropower system are likely to be necessary, regardless of the degree of change that can feasibly be achieved in the migration corridor.

Parameters relevant for survival through the hydropower system are presented in Table 5.

Table 5. Hydropower scenario survival rates. For Snake River ESUs, these reflect rates from Lower Granite Dam to the Bonneville Dam tailrace. Wenatchee rates reflect survival through both Lower Columbia and "Mid-Columbia" PUD dams. Mid-Columbia River rates are through the John Day, The Dalles and Bonneville dams. Status and Current Operations rates are derived from Williams et al. 2005. For proposed action, we present only the proportional change from current operations, as Compass does not provide individual component parameters.

| ESU | Description | Status (1980-2001) | Current Operations | Proposed Action |
|---|---|---|---|---|
| Snake River Spring / Summer Chinook | In-river | 0.334 | 0.472 | |
| | % transported | 0.600 | 0.800 | |
| | D mean | 0.466 | 0.466 | |
| | High D | 2.10 | 2.10 | |
| | D var | 0.134 | 0.134 | |
| | Proportion Change | | | 1.065 |
| Upper Columbia River Spring Chinook – Wenatchee | In-river survival | 0.441 | 0.525 | |
| | Proportion Change | | | 1.283 |
| Mid-Columbia River Steelhead (Umatilla) | John Day to Bonneville Survival | 0.608 | 0.644 | |
| | Proportion Change | | | 1.111 |
| Snake River Steelhead | In-river | 0.265 | 0.268 | |
| | % transported | 0.887 | 0.838 | |
| | D | 0.783 | 0.783 | |
| | Proportion Change | | | 0.911 |

## 5. Modeled scenarios – Environmental conditions

Because Pacific salmon population dynamics appear to be driven by ocean climate conditions (Mantua et al. 1997), we varied the environmental time series that we used in our model runs and simulated three different scenarios, chosen to bracket a range of potential futures:

1) First, we applied the time series that applied to our current status assessments (1980-2001) (Baseline). This, like the baseline hydropower scenario allowed us to calibrate the proportional change in life-cycle survival rates between alternate scenarios, and was chosen to reflect the conditions under which current status assessments were conducted.

2) Next, we simulated conditions equivalent to those seen over the entire historical time period. We applied PDO and upwelling conditions seen over the past 60 years (the longest time period available for all predictors). We calculated WTT for all projections using currently existing dams and reservoirs coupled with historical flows. This allowed us to assess the potential change in population status that might occur under an environmental regime more like that seen over the last 60 years (Historical).

3) The final scenario simulated “Warm PDO” environmental conditions. For these simulations, we used only environmental conditions rates seen during the period from 1977-1997, a period of below average early ocean survival and higher than average PDO values. [Note that we used indicators in addition to PDO for this and all other scenarios, but defined the time period used by average PDO values.]

The Historical and Warm PDO scenarios serve as endpoints for a plausible range of potential futures and serve not as a prediction of future conditions but rather as an informed sensitivity analysis.

## 6. Scenarios Evaluated and Response Variables

We evaluated all possible combinations of the hydropower and ocean condition scenarios (Table 6), beginning each simulation with the population-specific geometric mean number of spawners seen in the most recent available five years of data, and using the mean age structure of the population to back-fill the other age classes. We ran the model 100,000 times (each time producing a single trajectory) per scenario to derive means, standard deviations, and accurate probabilities where appropriate.

Table 6. Climate and hydropower survival scenarios used in evaluating the biological feasibility of Interior Columbia salmon and steelhead populations meeting IC-TRT viability goals.

| Hydro Scenario | Environmental Scenario |
|---|---|
| Current (Williams et al. 2005) | Last 100 years |
| | "Bad" conditions only |
| | Most recent 25 years |
| Current + anticipated mean hydro improvements (Compass model) | Last 100 years |
| | "Bad" conditions only |
| | Most recent 25 years |

We used several response variables to assess population status in each of these model runs.

- Geometric mean spawner abundance (across a single simulated trajectory). We reported the mean and standard deviation (across simulations) of this statistic.

- We also calculated the 95% confidence intervals of spawner abundances observed within a single trajectory and report the mean confidence interval calculated across simulations.

- Median spawner abundance. We chose median spawner abundance as a reasonable indicator of the population equilibrium value and reported the mean and standard deviation across simulations.

- Intrinsic productivity. We evaluated intrinsic productivity as the geometric mean of productivities observed at spawner levels below 50% of median spawners as determined with the current climate and hydro scenarios. We reported the mean (across simulations) and standard deviation of this measure. We examined a number of ways to calculate intrinsic productivity from the modeling results. This one was most consistent with the intrinsic productivity metric we used in our current status assessments.

- Viability. Under each of the environmental and climate scenarios, we evaluate whether the populations could achieve levels of abundance and productivity sufficient to meet IC-TRT viability criteria corresponding to the 5% extinction risk threshold (Interior Columbia Technical Recovery Team 2007c). To do this, we compared the median spawner number and intrinsic productivity generated for each scenario (described above) with our viability curves to determine whether these criteria had been met. Although we make direct comparisons between matrix model abundance/productivity estimates and the ICTRT 5% extinction risk A/P criteria, these comparisons should be viewed with caution. The ICTRT criteria for abundance and productivity are expressed in terms of viability curves – combinations of average abundance and intrinsic productivity that project to achieve a target risk level. The viability curves were developed using average ESU productivity variance, autocorrelation, and age-structure which do not specifically equal values for any individual population. In addition, the underlying stock-recruitment function, initial population abundance, and recruitment failure thresholds are different between the ICTRT viability curve generating method and the matrix model. These differences can produce different extinction risk probabilities between the two approaches for the same abundance/productivity values.

- Probability of quasi-extinction. We calculated the probability that the population fell below an average of 50 spawners per year over a four year period during the simulation. This metric is reported merely as an indicator of overall population status, not as a viability goal or target. For a particular population, projected extinction risks in the matrix model are a function of the life cycle survival and capacity characteristics and the starting abundance. All of the climate and hydro scenarios were run using a recent average geometric mean escapement as a starting abundance. In some cases, the starting abundance levels are extremely low, contributing to relatively high immediate extinction risks. The ICTRT viability curves are combinations of abundance and productivity that, if achieved, would project to the target extinction risk. These matrix model outputs estimate the long term projected performance of the population if it avoids extinction during the transition period from current conditions to modeled conditions.

Of these response variables, intrinsic productivity is among the most important, since productivity at low densities is a key determinant of extinction risk.

This modeling effort was undertaken largely to assess the potential for changes to out-migration survival or in environmental conditions to affect population status. To evaluate these effects, we conducted a GLM (general linear model) analysis, using the intrinsic productivity at 100 years from each modeled scenario as a response variable and ESU, hydropower scenario and environmental scenario as predictor variables. The model also included all interaction terms. To test the significance of hydropower scenarios and environmental scenarios within ESUs, we estimated reduced models separately for each ESU excluding the "100% survival" hydropower scenario, which is known to be unrealistic and increased the variance of the model. We conducted post-hoc pairwise comparisons with a Bonferroni correction between all hydropower scenarios and between all environmental scenarios.

## III. Results

A complete tabulation of response metrics from our analyses is presented in Tables 7a-c, and population-specific results are presented in Figures 6 a-e and 7 a-e. Under the parameters and model structure we used, all of the factors we tested – hydropower scenarios, climate scenarios and time frame over which the scenarios were evaluated – had significant effects on population intrinsic productivity (Table 8) but sometimes in different directions for different ESUs, as discussed more fully below. In addition, there was a significant interaction between the response to climate and hydropower scenarios.

Table 7 a: 100 year model runs

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESU | Population | Climate scenario | Hydropower system scenario | Mean | Standard deviation (across simulations) | Lower confidence limit | Upper confidence limit | Median | Standard deviation | Mean R/S at all densities | Standard deviation of R/S at all densities | Mean R/S at low densities | Standard deviation of R/S at low densities | Probability of quasi extinction | Viability |
| Snake River Spring/Summer Chinook | Catherine Creek (high hatchery years excluded) | Warm PDO | Baseline | 167.9 | 93.3 | 8.5 | 3328.8 | 175 | 106.8 | 0.624 | 0.055 | 0.753 | 0.121 | 0.815 | N |
| | | | Current Ops | 252.2 | 118.7 | 12.9 | 4930.1 | 266.7 | 139.2 | 0.645 | 0.055 | 0.844 | 0.153 | 0.676 | N |
| | | | Projected BiOp | 300.9 | 131.1 | 15.6 | 5788.3 | 320.8 | 155.9 | 0.656 | 0.055 | 0.895 | 0.172 | 0.604 | N |
| | | | 100% Survival | 1082.5 | 271.2 | 67.2 | 17447.1 | 1262 | 349.6 | 0.781 | 0.053 | 1.808 | 0.66 | 0.224 | Y |
| | | Baseline | Baseline | 283.1 | 125 | 14.8 | 5427.4 | 303.5 | 149.3 | 0.666 | 0.057 | 0.883 | 0.172 | 0.642 | N |
| | | | Current Ops | 393.5 | 151.5 | 20.7 | 7484.8 | 428.9 | 184 | 0.684 | 0.057 | 0.994 | 0.222 | 0.513 | N |
| | | | Projected BiOp | 456.3 | 165.1 | 24.3 | 8572.9 | 500.7 | 201.5 | 0.695 | 0.056 | 1.059 | 0.251 | 0.458 | N |
| | | | 100% Survival | 1443.2 | 323.8 | 84.6 | 24631.1 | 1674.5 | 414.7 | 0.803 | 0.054 | 2.199 | 1.024 | 0.168 | Y |
| | | Historical | Baseline | 708.1 | 235.2 | 33.9 | 14795.6 | 805.1 | 294.4 | 0.716 | 0.06 | 1.201 | 0.347 | 0.326 | N |
| | | | Current Ops | 905 | 274.3 | 43.6 | 18798.2 | 1039.4 | 346.7 | 0.727 | 0.059 | 1.356 | 0.456 | 0.254 | Y |
| | | | Projected BiOp | 1014.6 | 293.9 | 49.3 | 20860.5 | 1170.1 | 373.8 | 0.734 | 0.059 | 1.448 | 0.523 | 0.222 | Y |
| | | | 100% Survival | 2536 | 510.4 | 138.5 | 46442.7 | 3049.1 | 703.5 | 0.83 | 0.056 | 3.301 | 2.348 | 0.078 | Y |
| | Catherine Creek | Warm PDO | Baseline | 357.6 | 99.5 | 31.3 | 4087.4 | 383.7 | 120.2 | 0.761 | 0.047 | 0.981 | 0.116 | 0.383 | N |
| | | | Current Ops | 471.7 | 118.3 | 39.7 | 5609.1 | 512 | 144.5 | 0.769 | 0.047 | 1.083 | 0.146 | 0.299 | N |
| | | | Projected BiOp | 534.7 | 127.5 | 44.7 | 6396.3 | 584.7 | 157.6 | 0.776 | 0.047 | 1.143 | 0.164 | 0.267 | N |
| | | | 100% Survival | 1434.3 | 234.9 | 126.4 | 16274.1 | 1682.6 | 311.7 | 0.872 | 0.046 | 2.25 | 0.609 | 0.079 | Y |
| | | Baseline | Baseline | 506.2 | 122.9 | 43.1 | 5949.8 | 557.1 | 150.6 | 0.794 | 0.049 | 1.14 | 0.169 | 0.294 | N |
| | | | Current Ops | 643.6 | 144.6 | 52.8 | 7851.1 | 715 | 178.1 | 0.802 | 0.05 | 1.271 | 0.216 | 0.241 | N |
| | | | Projected BiOp | 719 | 155.9 | 58.5 | 8838.5 | 802.7 | 192.7 | 0.808 | 0.05 | 1.345 | 0.244 | 0.215 | N |
| | | | 100% Survival | 1814.7 | 281 | 144.9 | 22729.2 | 2096 | 366.7 | 0.89 | 0.047 | 2.743 | 0.927 | 0.059 | Y |
| | | Historical | Baseline | 1017.1 | 215.8 | 73.7 | 14040.2 | 1165.5 | 278 | 0.816 | 0.054 | 1.467 | 0.328 | 0.133 | N |
| | | | Current Ops | 1240.9 | 249.8 | 87.7 | 17562.7 | 1424.5 | 325.4 | 0.819 | 0.054 | 1.646 | 0.422 | 0.106 | N |
| | | | Projected BiOp | 1363.9 | 266 | 95.9 | 19399.8 | 1570.3 | 349.4 | 0.823 | 0.054 | 1.751 | 0.487 | 0.093 | N |
| | | | 100% Survival | 3000.8 | 452.7 | 215.2 | 41844 | 3559.6 | 656.3 | 0.899 | 0.052 | 3.995 | 2.186 | 0.026 | Y |
| | South Fork Salmon River | Warm PDO | Baseline | 596.8 | 114 | 99.5 | 3580.4 | 614.8 | 122.4 | 0.749 | 0.036 | 0.911 | 0.084 | 0.001 | N |
| | | | Current Ops | 764.9 | 131.8 | 128.2 | 4562.4 | 777 | 144 | 0.758 | 0.036 | 0.993 | 0.106 | 0 | N |
| | | | Projected BiOp | 855.3 | 139.6 | 146.1 | 5007.2 | 867.8 | 156.5 | 0.766 | 0.036 | 1.039 | 0.119 | 0 | N |
| | | | 100% Survival | 2091.8 | 220.7 | 479.8 | 9118.8 | 2239.9 | 273 | 0.871 | 0.033 | 1.985 | 0.541 | 0 | Y |
| | | Baseline | Baseline | 807.8 | 133.3 | 136.9 | 4766.1 | 835.3 | 150 | 0.784 | 0.038 | 1.048 | 0.129 | 0 | N |
| | | | Current Ops | 1003.1 | 153.7 | 169.7 | 5928.4 | 1034.9 | 178 | 0.794 | 0.038 | 1.154 | 0.166 | 0 | N |
| | | | Projected BiOp | 1110.2 | 163.1 | 189.6 | 6500.4 | 1146.3 | 190.9 | 0.8 | 0.038 | 1.213 | 0.189 | 0 | N |
| | | | 100% Survival | 2585.4 | 254.2 | 516.6 | 12939.4 | 2698.4 | 308.5 | 0.893 | 0.034 | 2.364 | 0.848 | 0 | Y |
| | | Historical | Baseline | 1519.7 | 227.9 | 230 | 10043.3 | 1629.7 | 278.8 | 0.81 | 0.044 | 1.216 | 0.221 | 0 | N |
| | | | Current Ops | 1826.6 | 260 | 275.3 | 12119.8 | 1953.8 | 323 | 0.814 | 0.044 | 1.336 | 0.289 | 0 | N |
| | | | Projected BiOp | 1990.9 | 274.7 | 303.6 | 13055.5 | 2132 | 345.2 | 0.819 | 0.044 | 1.406 | 0.335 | 0 | Y |
| | | | 100% Survival | 4144.2 | 423.4 | 749.9 | 22901.9 | 4502.6 | 593.5 | 0.907 | 0.04 | 3.14 | 1.847 | 0 | Y |

Table 7 a: 100 year model runs, continued

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ESU** | **Population** | **Climate scenario** | **Hydropower system scenario** | **Mean** | **Standard deviation (across simulations)** | **Lower confidence limit** | **Upper confidence limit** | **Median** | **Standard deviation** | **Mean R/S at all densities** | **Standard deviation of R/S at all densities** | **Mean R/S at low densities** | **Standard deviation of R/S at low densities** | **Probability of quasi extinction** | **Viability** |
| Snake River Spring/Summer Chinook | Marsh Creek | Warm PDO | Baseline | 132.6 | 40.4 | 14.2 | 1237.7 | 135.8 | 45.4 | 0.712 | 0.045 | 0.871 | 0.103 | 0.77 | N |
| | | | Current Ops | 180.2 | 47.7 | 19.4 | 1674.3 | 186.2 | 55 | 0.726 | 0.045 | 0.962 | 0.131 | 0.571 | N |
| | | | Projected BiOp | 206.4 | 51.3 | 22.6 | 1888.7 | 214.5 | 59.9 | 0.736 | 0.045 | 1.014 | 0.148 | 0.477 | N |
| | | | 100% Survival | 579.3 | 88.6 | 79 | 4251 | 646.1 | 111.2 | 0.853 | 0.041 | 2.02 | 0.63 | 0.099 | Y |
| | | Baseline | Baseline | 194.6 | 49 | 21.4 | 1770.9 | 204.6 | 57.3 | 0.751 | 0.047 | 1.01 | 0.152 | 0.57 | N |
| | | | Current Ops | 251.4 | 56.9 | 27.6 | 2294.7 | 266.6 | 67.4 | 0.764 | 0.046 | 1.124 | 0.197 | 0.412 | N |
| | | | Projected BiOp | 282.7 | 61.1 | 31.3 | 2553 | 301.1 | 72.7 | 0.773 | 0.046 | 1.189 | 0.223 | 0.342 | N |
| | | | 100% Survival | 734.8 | 102.3 | 91 | 5929.4 | 807.8 | 126.7 | 0.876 | 0.042 | 2.45 | 0.999 | 0.073 | Y |
| | | Historical | Baseline | 403.7 | 84.3 | 39.7 | 4108.7 | 446.3 | 104.3 | 0.788 | 0.05 | 1.267 | 0.285 | 0.282 | N |
| | | | Current Ops | 497.1 | 96.5 | 48.8 | 5063.9 | 551.5 | 120.8 | 0.795 | 0.05 | 1.417 | 0.381 | 0.188 | N |
| | | | Projected BiOp | 547.2 | 102.3 | 54.3 | 5516.9 | 609.1 | 129.4 | 0.802 | 0.05 | 1.505 | 0.436 | 0.154 | N |
| | | | 100% Survival | 1214.5 | 160.9 | 138.5 | 10653.7 | 1389.5 | 225 | 0.898 | 0.046 | 3.545 | 2.237 | 0.031 | Y |
| Upper Columbia River Spring Chinook | Wenatchee River | Warm PDO | Baseline | 26.2 | 24.7 | 0.4 | 1719.8 | 27 | 28.2 | 0.563 | 0.04 | 0.572 | 0.044 | 0.998 | N |
| | | | Current Ops | 105.4 | 71.5 | 6.9 | 1611.9 | 109 | 80 | 0.652 | 0.041 | 0.675 | 0.054 | 0.861 | N |
| | | | Projected BiOp | 187.9 | 105.4 | 19.5 | 1811.4 | 196.2 | 116.7 | 0.692 | 0.04 | 0.736 | 0.068 | 0.563 | N |
| | | | 100% Survival | 1629.2 | 319.7 | 300.1 | 8843.5 | 1677.9 | 362.7 | 0.829 | 0.037 | 2.188 | 1.2 | 0 | N |
| | | Baseline | Baseline | 126 | 78.9 | 7.3 | 2161.4 | 141.4 | 94.9 | 0.599 | 0.038 | 0.615 | 0.05 | 0.73 | N |
| | | | Current Ops | 317.1 | 133.7 | 31.5 | 3189.1 | 351.9 | 154 | 0.667 | 0.038 | 0.699 | 0.079 | 0.174 | N |
| | | | Projected BiOp | 456.8 | 159.2 | 52.4 | 3986.5 | 499.4 | 178.1 | 0.696 | 0.039 | 0.755 | 0.11 | 0.043 | N |
| | | | 100% Survival | 2129 | 348.3 | 321.6 | 14092.8 | 2251.2 | 415.4 | 0.816 | 0.038 | 2.789 | 1.415 | 0 | Y |
| | | Historical | Baseline | 688.9 | 239 | 57 | 8332.4 | 707.2 | 244 | 0.716 | 0.042 | 0.847 | 0.129 | 0.108 | N |
| | | | Current Ops | 1170.7 | 323.2 | 113.7 | 12055 | 1158.5 | 338.6 | 0.752 | 0.041 | 1.005 | 0.26 | 0.007 | N |
| | | | Projected BiOp | 1470.9 | 366.3 | 151 | 14332.5 | 1450.4 | 396.9 | 0.767 | 0.041 | 1.128 | 0.401 | 0.001 | N |
| | | | 100% Survival | 1536.3 | 374.7 | 171.8 | 14015.4 | 4568.9 | 823.7 | 0.8 | 0.0 | 3.8 | 3.3 | 0 | Y |
| Mid-Columbia River Steelhead | Umatilla River | Warm PDO | Baseline | 1225.2 | 110.9 | 301.3 | 4982 | 1238 | 136.4 | 0.867 | 0.033 | 0.976 | 0.055 | 0 | N |
| | | | Current Ops | 1308.9 | 116.4 | 325.5 | 5263 | 1325.3 | 143.7 | 0.87 | 0.033 | 0.995 | 0.058 | 0 | N |
| | | | Projected BiOp | 1473.3 | 127 | 374.1 | 5802.8 | 1495.4 | 158.5 | 0.877 | 0.032 | 1.034 | 0.066 | 0 | N |
| | | | 100% survival | 2123.8 | 170 | 567.4 | 7948.8 | 2165 | 211.7 | 0.898 | 0.033 | 1.2 | 0.093 | 0 | Y |
| | | Baseline | Baseline | 1318.7 | 118.5 | 320.6 | 5425.1 | 1355.7 | 147.5 | 0.871 | 0.029 | 1.002 | 0.058 | 0 | N |
| | | | Current Ops | 1407.6 | 124.4 | 345.4 | 5736.1 | 1449.8 | 155.5 | 0.875 | 0.03 | 1.025 | 0.063 | 0 | N |
| | | | Projected BiOp | 1582.3 | 136.7 | 395.6 | 6328.7 | 1633.4 | 171.7 | 0.881 | 0.03 | 1.072 | 0.072 | 0 | N |
| | | | 100% survival | 2276.6 | 182.1 | 595.9 | 8697.3 | 2360.6 | 233.6 | 0.902 | 0.029 | 1.276 | 0.11 | 0 | Y |
| | | Historical | Baseline | 1498.6 | 141.1 | 308.4 | 7281.4 | 1507.3 | 169.4 | 0.863 | 0.029 | 1.107 | 0.089 | 0 | N |
| | | | Current Ops | 1599.4 | 148 | 332.4 | 7696.7 | 1609.8 | 178.2 | 0.866 | 0.029 | 1.138 | 0.095 | 0 | N |
| | | | Projected BiOp | 1795.1 | 162 | 378.5 | 8512.6 | 1808.5 | 195.6 | 0.872 | 0.028 | 1.201 | 0.107 | 0 | N |
| | | | 100% survival | 2575.3 | 217.4 | 563.8 | 11763.4 | 2600.6 | 266.3 | 0.891 | 0.028 | 1.467 | 0.158 | 0 | Y |

Table 7 a: 100 year model runs, continued.

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESU | Population | Climate scenario | Hydropower system scenario | Mean | Standard deviation (across simulations) | Lower confidence limit | Upper confidence limit | Median | Standard deviation | Mean R/S at all densities | Standard deviation of R/S at all densities | Mean R/S at low densities | Standard deviation of R/S at low densities | Probability of quasi extinction | Viability |
| Snake River Steelhead | Little Salmon River | Warm PDO | Baseline | 67.6 | 6 | 18.4 | 248.2 | 68.5 | 7.2 | 0.912 | 0.041 | 1.49 | 0.167 | 1 | N |
| | | | Current Ops | 65 | 5.8 | 17.7 | 238.5 | 66 | 6.9 | 0.91 | 0.041 | 1.45 | 0.158 | 1 | N |
| | | | Projected BiOp | 58.6 | 5.3 | 16 | 215.2 | 59.5 | 6.4 | 0.904 | 0.041 | 1.355 | 0.138 | 1 | N |
| | | | 100% survival | 93.5 | 8.1 | 25.8 | 338.9 | 93.7 | 9.1 | 0.93 | 0.041 | 1.867 | 0.267 | 0.97 | N |
| | | Baseline | Baseline | 69.9 | 6.4 | 18.3 | 266.8 | 70.6 | 7.6 | 0.911 | 0.036 | 1.52 | 0.171 | 1 | N |
| | | | Current Ops | 67.2 | 6.2 | 17.6 | 256.3 | 67.9 | 7.4 | 0.909 | 0.036 | 1.48 | 0.162 | 1 | N |
| | | | Projected BiOp | 60.6 | 5.6 | 15.9 | 231.5 | 61.3 | 6.8 | 0.904 | 0.036 | 1.384 | 0.141 | 1 | N |
| | | | 100% survival | 96.6 | 8.4 | 26.4 | 354 | 96.7 | 9.5 | 0.93 | 0.035 | 1.886 | 0.27 | 0.964 | N |
| | | Historical | Baseline | 115 | 11.4 | 25.6 | 516.7 | 117.8 | 14 | 0.922 | 0.047 | 1.812 | 0.307 | 0.979 | N |
| | | | Current Ops | 110.7 | 11.1 | 24.7 | 497.2 | 113.5 | 13.3 | 0.92 | 0.047 | 1.77 | 0.289 | 0.986 | N |
| | | | Projected BiOp | 100.4 | 10.1 | 22.3 | 451.4 | 103.5 | 11.8 | 0.915 | 0.047 | 1.672 | 0.251 | 0.995 | N |
| | | | 100% survival | 156 | 15 | 35.2 | 691 | 158.2 | 19.1 | 0.939 | 0.046 | 2.228 | 0.531 | 0.72 | N |

Table 7 b: 50 year model runs

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESU | Population | Climate scenario | Hydropower system scenario | Mean | Standard deviation (across simulations) | Lower confidence limit | Upper confidence limit | Median | Standard deviation | Mean R/S at all densities | Standard deviation of R/S at all densities | Mean R/S at low densities | Standard deviation of R/S at low densities | Probability of quasi extinction | Viability |
| Snake River Spring/Summer Chinook | Catherine Creek (high hatchery years excluded) | Warm PDO | Baseline | 140.7 | 96.8 | 8.5 | 2330.1 | 145.8 | 113.4 | 0.659 | 0.095 | 0.777 | 0.188 | 0.723 | N |
| | | | Current Ops | 199.1 | 122.4 | 11.3 | 3508.8 | 209.4 | 149.2 | 0.697 | 0.097 | 0.878 | 0.233 | 0.608 | N |
| | | | Projected BiOp | 232.7 | 135.7 | 12.8 | 4214.6 | 247.6 | 168.9 | 0.717 | 0.098 | 0.938 | 0.263 | 0.555 | N |
| | | | 100% Survival | 769.6 | 287.6 | 36.7 | 16147.8 | 951.5 | 422.3 | 0.914 | 0.103 | 1.92 | 0.925 | 0.224 | Y |
| | | Baseline | Baseline | 222 | 130.9 | 12.5 | 3929.9 | 236.7 | 162 | 0.724 | 0.098 | 0.924 | 0.26 | 0.579 | N |
| | | | Current Ops | 299.1 | 159.6 | 15.8 | 5657.9 | 325.9 | 204.4 | 0.757 | 0.1 | 1.05 | 0.338 | 0.478 | N |
| | | | Projected BiOp | 343.8 | 174.4 | 17.7 | 6686.8 | 379.9 | 227.9 | 0.774 | 0.101 | 1.124 | 0.382 | 0.436 | N |
| | | | 100% Survival | 1035.1 | 345.2 | 44.5 | 24079.2 | 1297.1 | 509.1 | 0.946 | 0.103 | 2.36 | 1.386 | 0.169 | Y |
| | | Historical | Baseline | 538.3 | 252.2 | 23.6 | 12276.1 | 619.7 | 352.4 | 0.812 | 0.113 | 1.339 | 0.595 | 0.296 | Y |
| | | | Current Ops | 682.2 | 295.4 | 28.5 | 16315.3 | 803.7 | 425 | 0.833 | 0.114 | 1.541 | 0.793 | 0.237 | Y |
| | | | Projected BiOp | 759.7 | 317.3 | 31.3 | 18443.9 | 906.2 | 460.9 | 0.846 | 0.114 | 1.657 | 0.894 | 0.212 | Y |
| | | | 100% Survival | 1848.5 | 544.8 | 69.6 | 49125.1 | 2459.9 | 905.8 | 0.996 | 0.115 | 3.691 | 2.967 | 0.079 | Y |
| | Catherine Creek | Warm PDO | Baseline | 273.3 | 107.7 | 22.6 | 3299.5 | 295 | 137.6 | 0.844 | 0.086 | 1.037 | 0.176 | 0.372 | N |
| | | | Current Ops | 356.9 | 128.2 | 26.7 | 4775.6 | 394.7 | 169.2 | 0.865 | 0.088 | 1.155 | 0.221 | 0.297 | N |
| | | | Projected BiOp | 403.5 | 139.3 | 29.3 | 5561.9 | 452.8 | 186.3 | 0.879 | 0.088 | 1.223 | 0.246 | 0.266 | N |
| | | | 100% Survival | 1059.3 | 258.5 | 65.5 | 17127.4 | 1367.7 | 392.4 | 1.035 | 0.091 | 2.435 | 0.822 | 0.079 | Y |
| | | Baseline | Baseline | 386 | 134.9 | 29 | 5133.6 | 434.1 | 179.3 | 0.893 | 0.088 | 1.216 | 0.248 | 0.295 | N |
| | | | Current Ops | 486.5 | 157.9 | 33.7 | 7021.8 | 559 | 213.5 | 0.913 | 0.09 | 1.364 | 0.318 | 0.242 | N |
| | | | Projected BiOp | 543.5 | 170 | 36.5 | 8083.8 | 631.7 | 232.6 | 0.925 | 0.09 | 1.452 | 0.359 | 0.214 | N |
| | | | 100% Survival | 1351.9 | 311.1 | 74.6 | 24504.4 | 1734.2 | 468.4 | 1.062 | 0.089 | 2.991 | 1.262 | 0.06 | Y |
| | | Historical | Baseline | 782 | 241 | 46 | 13281.1 | 940.8 | 363.8 | 0.943 | 0.106 | 1.679 | 0.572 | 0.133 | N |
| | | | Current Ops | 951.4 | 275.5 | 52.8 | 17159.2 | 1163.3 | 425.7 | 0.954 | 0.108 | 1.908 | 0.737 | 0.107 | N |
| | | | Projected BiOp | 1040.7 | 294 | 56.5 | 19170.9 | 1283.6 | 458.4 | 0.964 | 0.108 | 2.05 | 0.852 | 0.096 | Y |
| | | | 100% Survival | 2257.5 | 484.3 | 107.7 | 47307.5 | 3018.8 | 864.3 | 1.09 | 0.108 | 4.56 | 2.846 | 0.026 | Y |
| | South Fork Salmon River | Warm PDO | Baseline | 600.9 | 149 | 106.6 | 3387.9 | 616.6 | 156.9 | 0.756 | 0.06 | 0.917 | 0.13 | 0 | N |
| | | | Current Ops | 751.2 | 173.5 | 131.7 | 4285.7 | 758.4 | 186.8 | 0.774 | 0.061 | 1.007 | 0.164 | 0 | N |
| | | | Projected BiOp | 831.1 | 183.1 | 147.2 | 4693.2 | 837 | 202.8 | 0.785 | 0.061 | 1.057 | 0.183 | 0 | N |
| | | | 100% Survival | 1918.8 | 288.6 | 403 | 9134.8 | 2095.6 | 373.3 | 0.93 | 0.059 | 2.09 | 0.768 | 0 | Y |
| | | Baseline | Baseline | 791.2 | 172.6 | 138.9 | 4507.6 | 812 | 191.1 | 0.801 | 0.061 | 1.066 | 0.19 | 0 | N |
| | | | Current Ops | 966.3 | 198.4 | 166.7 | 5601.7 | 988.2 | 230.7 | 0.818 | 0.061 | 1.181 | 0.248 | 0 | N |
| | | | Projected BiOp | 1061.7 | 210.9 | 183.5 | 6141.6 | 1087.8 | 249.5 | 0.829 | 0.061 | 1.246 | 0.28 | 0 | N |
| | | | 100% Survival | 2362.5 | 330.6 | 428.6 | 13022.1 | 2528.4 | 421.9 | 0.96 | 0.056 | 2.539 | 1.205 | 0 | Y |
| | | Historical | Baseline | 1453.7 | 303.7 | 223.3 | 9464.3 | 1544.3 | 383.9 | 0.844 | 0.08 | 1.291 | 0.399 | 0 | N |
| | | | Current Ops | 1730.1 | 342.7 | 259.8 | 11520.9 | 1844.6 | 446.8 | 0.855 | 0.081 | 1.45 | 0.563 | 0 | Y |
| | | | Projected BiOp | 1873.1 | 360.6 | 281.7 | 12454.9 | 2004.6 | 477.6 | 0.864 | 0.08 | 1.548 | 0.764 | 0 | Y |
| | | | 100% Survival | 3758.8 | 530.4 | 603.3 | 23417.9 | 4217.5 | 825.7 | 0.987 | 0.077 | 3.595 | 2.521 | 0 | Y |

Table 7 b. 50 year model runs, continued.

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ESU** | **Population** | **Climate scenario** | **Hydropower system scenario** | **Mean** | **Standard deviation (across simulations)** | **Lower confidence limit** | **Upper confidence limit** | **Median** | **Standard deviation** | **Mean R/S at all densities** | **Standard deviation of R/S at all densities** | **Mean R/S at low densities** | **Standard deviation of R/S at low densities** | **Probability of quasi extinction** | **Viability** |
| Snake River Spring/Summer Chinook | Marsh Creek | Warm PDO | Baseline | 121.6 | 48 | 13.9 | 1060.6 | 123.6 | 54.4 | 0.744 | 0.077 | 0.897 | 0.161 | 0.628 | N |
| | | | Current Ops | 159.8 | 56.9 | 17.6 | 1453.8 | 164.2 | 67.4 | 0.77 | 0.078 | 0.999 | 0.202 | 0.473 | N |
| | | | Projected BiOp | 180.8 | 61.3 | 19.7 | 1657.1 | 187.3 | 73.8 | 0.786 | 0.078 | 1.058 | 0.227 | 0.407 | N |
| | | | 100% Survival | 477.6 | 107.1 | 52.9 | 4310.7 | 559.2 | 146.8 | 0.956 | 0.077 | 2.161 | 0.895 | 0.098 | Y |
| | | Baseline | Baseline | 172.2 | 58.9 | 19.1 | 1553.1 | 180.1 | 70.9 | 0.797 | 0.078 | 1.052 | 0.231 | 0.477 | N |
| | | | Current Ops | 218.9 | 68.7 | 23.3 | 2058.1 | 232.3 | 84.6 | 0.821 | 0.079 | 1.182 | 0.299 | 0.355 | N |
| | | | Projected BiOp | 243.5 | 72.9 | 25.7 | 2309.4 | 260.9 | 91.4 | 0.835 | 0.079 | 1.256 | 0.332 | 0.309 | N |
| | | | 100% Survival | 606.7 | 123.9 | 59.9 | 6142.1 | 706.5 | 168.1 | 0.987 | 0.076 | 2.672 | 1.428 | 0.074 | Y |
| | | Historical | Baseline | 350.3 | 103.2 | 32.4 | 3793.6 | 390.9 | 140.4 | 0.86 | 0.094 | 1.411 | 0.517 | 0.228 | N |
| | | | Current Ops | 426.4 | 117.1 | 38.1 | 4775 | 481.8 | 163 | 0.875 | 0.095 | 1.609 | 0.684 | 0.164 | N |
| | | | Projected BiOp | 467.3 | 123.7 | 41.4 | 5279 | 532.2 | 174.6 | 0.887 | 0.095 | 1.726 | 0.801 | 0.138 | N |
| | | | 100% Survival | 1003 | 189.7 | 87.8 | 11456.6 | 1233.6 | 310.8 | 1.026 | 0.092 | 4.023 | 2.898 | 0.031 | Y |
| Upper Columbia River Spring Chinook | Wenatchee River | Warm PDO | Baseline | 103.7 | 62.7 | 6.5 | 1662.6 | 108.9 | 74.9 | 0.547 | 0.053 | 0.567 | 0.066 | 0.982 | N |
| | | | Current Ops | 211.8 | 110.3 | 24.5 | 1831.4 | 225.2 | 127.5 | 0.63 | 0.056 | 0.675 | 0.094 | 0.701 | N |
| | | | Projected BiOp | 293.9 | 140.6 | 42.4 | 2039.4 | 312.6 | 157.8 | 0.671 | 0.057 | 0.746 | 0.125 | 0.388 | N |
| | | | 100% Survival | 1453.9 | 385.7 | 271.4 | 7789.1 | 1488.2 | 444.5 | 0.87 | 0.059 | 2.261 | 1.89 | 0 | N |
| | | Baseline | Baseline | 210 | 108.5 | 18.3 | 2407.8 | 241.3 | 134.1 | 0.583 | 0.052 | 0.613 | 0.085 | 0.57 | N |
| | | | Current Ops | 381.7 | 162.7 | 46.3 | 3145.6 | 428.6 | 186.4 | 0.658 | 0.054 | 0.717 | 0.144 | 0.114 | N |
| | | | Projected BiOp | 498.4 | 192.7 | 66.8 | 3718.3 | 547.8 | 211.2 | 0.693 | 0.055 | 0.793 | 0.211 | 0.028 | N |
| | | | 100% Survival | 1873.8 | 431.1 | 278.1 | 12624.6 | 1969.3 | 523.4 | 0.867 | 0.057 | 2.886 | 2.07 | 0 | N |
| | | Historical | Baseline | 755 | 336.8 | 72.6 | 7855.3 | 759.1 | 331.9 | 0.715 | 0.073 | 0.867 | 0.312 | 0.079 | N |
| | | | Current Ops | 1154.8 | 430.1 | 123.7 | 10782.7 | 1124.4 | 441.3 | 0.769 | 0.075 | 1.098 | 0.65 | 0.005 | N |
| | | | Projected BiOp | 1405.6 | 478.7 | 155.3 | 12724.1 | 1364.7 | 511.1 | 0.793 | 0.076 | 1.274 | 0.924 | 0.001 | N |
| | | | 100% Survival | 3873.1 | 834.7 | 430.4 | 34854.6 | 4032.2 | 1079.4 | 0.905 | 0.079 | 3.318 | 3.47 | 0 | Y |
| Mid-Columbia River Steelhead | Umatilla River | Warm PDO | Baseline | 1281.2 | 161.8 | 311.7 | 5265.5 | 1297.2 | 200.2 | 0.833 | 0.043 | 0.963 | 0.082 | 0 | N |
| | | | Current Ops | 1363.4 | 169.1 | 337.3 | 5511.3 | 1384.9 | 210.3 | 0.839 | 0.043 | 0.982 | 0.087 | 0 | N |
| | | | Projected BiOp | 1525.4 | 185.5 | 388 | 5997.9 | 1557.1 | 232.3 | 0.851 | 0.044 | 1.024 | 0.097 | 0 | N |
| | | | 100% survival | 2163 | 246.4 | 588.1 | 7955.5 | 2223.3 | 312.7 | 0.885 | 0.044 | 1.199 | 0.138 | 0 | Y |
| | | Baseline | Baseline | 1375.4 | 167 | 330.8 | 5718.2 | 1418.6 | 212 | 0.839 | 0.04 | 0.992 | 0.093 | 0 | N |
| | | | Current Ops | 1463.6 | 175.4 | 357.3 | 5996.1 | 1513.3 | 222.9 | 0.845 | 0.04 | 1.016 | 0.099 | 0 | N |
| | | | Projected BiOp | 1635.5 | 191 | 409.2 | 6536.9 | 1698.7 | 244.5 | 0.855 | 0.04 | 1.065 | 0.112 | 0 | N |
| | | | 100% survival | 2313.9 | 254 | 614.9 | 8706.3 | 2419.6 | 330.6 | 0.89 | 0.041 | 1.278 | 0.165 | 0 | Y |
| | | Historical | Baseline | 1562.3 | 210.3 | 321.9 | 7583.2 | 1577.9 | 256.6 | 0.834 | 0.067 | 1.102 | 0.144 | 0 | N |
| | | | Current Ops | 1660.6 | 220.2 | 346.2 | 7964.4 | 1679.7 | 268.3 | 0.84 | 0.067 | 1.134 | 0.153 | 0 | N |
| | | | Projected BiOp | 1854.1 | 241 | 394.7 | 8710.1 | 1881.3 | 294.6 | 0.851 | 0.067 | 1.2 | 0.171 | 0 | Y |
| | | | 100% survival | 2617.7 | 320.1 | 584.2 | 11729.1 | 2661.4 | 384.3 | 0.883 | 0.069 | 1.479 | 0.254 | 0 | Y |

Table 7 b. 50 year model runs, continued.

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESU | Population | Climate scenario | Hydropower system scenario | Mean | Standard deviation (across simulations) | Lower confidence limit | Upper confidence limit | Median | Standard deviation | Mean R/S at all densities | Standard deviation of R/S at all densities | Mean R/S at low densities | Standard deviation of R/S at low densities | Probability of quasi extinction | Viability |
| Snake River Steelhead | Little Salmon River | Warm PDO | Baseline | 67.6 | 6 | 18.4 | 248.2 | 68.5 | 7.2 | 0.912 | 0.041 | 1.49 | 0.167 | 1 | N |
| | | | Current Ops | 65 | 5.8 | 17.7 | 238.5 | 66 | 6.9 | 0.91 | 0.041 | 1.45 | 0.158 | 1 | N |
| | | | Projected BiOp | 58.6 | 5.3 | 16 | 215.2 | 59.5 | 6.4 | 0.904 | 0.041 | 1.355 | 0.138 | 1 | N |
| | | | 100% survival | 93.5 | 8.1 | 25.8 | 338.9 | 93.7 | 9.1 | 0.93 | 0.041 | 1.867 | 0.267 | 0.97 | N |
| | | Baseline | Baseline | 69.9 | 6.4 | 18.3 | 266.8 | 70.6 | 7.6 | 0.911 | 0.036 | 1.52 | 0.171 | 1 | N |
| | | | Current Ops | 67.2 | 6.2 | 17.6 | 256.3 | 67.9 | 7.4 | 0.909 | 0.036 | 1.48 | 0.162 | 1 | N |
| | | | Projected BiOp | 60.6 | 5.6 | 15.9 | 231.5 | 61.3 | 6.8 | 0.904 | 0.036 | 1.384 | 0.141 | 1 | N |
| | | | 100% survival | 96.6 | 8.4 | 26.4 | 354 | 96.7 | 9.5 | 0.93 | 0.035 | 1.886 | 0.27 | 0.964 | N |
| | | Historical | Baseline | 115 | 11.4 | 25.6 | 516.7 | 117.8 | 14 | 0.922 | 0.047 | 1.812 | 0.307 | 0.979 | N |
| | | | Current Ops | 110.7 | 11.1 | 24.7 | 497.2 | 113.5 | 13.3 | 0.92 | 0.047 | 1.77 | 0.289 | 0.986 | N |
| | | | Projected BiOp | 100.4 | 10.1 | 22.3 | 451.4 | 103.5 | 11.8 | 0.915 | 0.047 | 1.672 | 0.251 | 0.995 | N |
| | | | 100% survival | 156 | 15 | 35.2 | 691 | 158.2 | 19.1 | 0.939 | 0.046 | 2.228 | 0.531 | 0.72 | N |

Table 7 c: 25 year model runs

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESU | Population | Climate scenario | Hydropower system scenario | Mean | Standard deviation (across simulations) | Lower confidence limit | Upper confidence limit | Median | Standard deviation | Mean R/S at all densities | Standard deviation of R/S at all densities | Mean R/S at low densities | Standard deviation of R/S at low densities | Probability of quasi extinction | Viability |
| Snake River Spring/Summer Chinook | Catherine Creek (high hatchery years excluded) | Warm PDO | Baseline | 104.4 | 78.7 | 8.4 | 1303.3 | 105.5 | 94 | 0.721 | 0.186 | 0.814 | 0.307 | 0.653 | N |
| | | | Current Ops | 134.7 | 96.9 | 9.9 | 1834.9 | 136.8 | 121.2 | 0.789 | 0.2 | 0.928 | 0.375 | 0.564 | N |
| | | | Projected BiOp | 151.1 | 105.4 | 10.7 | 2129.3 | 154.5 | 135.1 | 0.824 | 0.206 | 0.989 | 0.41 | 0.52 | N |
| | | | 100% Survival | 408.9 | 222.5 | 19.5 | 8574.9 | 487.4 | 360.4 | 1.251 | 0.27 | 2.017 | 1.161 | 0.221 | N |
| | | Baseline | Baseline | 148.1 | 104.5 | 11 | 1993.4 | 152.3 | 132.3 | 0.826 | 0.209 | 0.987 | 0.421 | 0.535 | N |
| | | | Current Ops | 186.9 | 125.3 | 12.5 | 2789.2 | 195.2 | 166.1 | 0.897 | 0.222 | 1.136 | 0.559 | 0.458 | N |
| | | | Projected BiOp | 208.7 | 136.6 | 13.3 | 3266.7 | 220.5 | 186.3 | 0.934 | 0.229 | 1.216 | 0.61 | 0.423 | N |
| | | | 100% Survival | 551.6 | 276.1 | 21.4 | 14228.4 | 676.4 | 466.7 | 1.353 | 0.294 | 2.521 | 1.779 | 0.17 | N |
| | | Historical | Baseline | 361.4 | 266 | 20.8 | 6295.4 | 405.7 | 379 | 1.038 | 0.305 | 1.605 | 1.142 | 0.269 | N |
| | | | Current Ops | 441.4 | 311.4 | 22.4 | 8708.4 | 509.9 | 463 | 1.102 | 0.318 | 1.848 | 1.378 | 0.224 | N |
| | | | Projected BiOp | 483.7 | 332.8 | 23.5 | 9966.8 | 567 | 502.7 | 1.138 | 0.325 | 1.992 | 1.557 | 0.206 | N |
| | | | 100% Survival | 1076.2 | 626.4 | 34.2 | 33884.5 | 1513.3 | 1162 | 1.525 | 0.381 | 4.061 | 3.571 | 0.078 | Y |
| | Catherine Creek | Warm PDO | Baseline | 171.8 | 86.9 | 16.6 | 1782.1 | 177 | 114.4 | 1.004 | 0.188 | 1.125 | 0.293 | 0.37 | N |
| | | | Current Ops | 216.9 | 104.6 | 18 | 2616.8 | 228.9 | 144.8 | 1.074 | 0.201 | 1.264 | 0.353 | 0.297 | N |
| | | | Projected BiOp | 241.2 | 113.5 | 18.8 | 3101.8 | 258.5 | 161.9 | 1.111 | 0.205 | 1.344 | 0.39 | 0.262 | N |
| | | | 100% Survival | 584.5 | 213.1 | 28.8 | 11878.9 | 763 | 385.6 | 1.526 | 0.255 | 2.61 | 1.054 | 0.079 | N |
| | | Baseline | Baseline | 234.5 | 111.4 | 19.5 | 2827 | 251.4 | 156.3 | 1.121 | 0.213 | 1.341 | 0.404 | 0.294 | N |
| | | | Current Ops | 289.8 | 131.7 | 20.8 | 4031 | 319.6 | 194.5 | 1.186 | 0.226 | 1.52 | 0.514 | 0.239 | N |
| | | | Projected BiOp | 319 | 141.1 | 21.5 | 4723.4 | 355.9 | 211.9 | 1.224 | 0.231 | 1.619 | 0.57 | 0.215 | N |
| | | | 100% Survival | 753.7 | 257.3 | 31.2 | 18201.4 | 1004.5 | 481.1 | 1.604 | 0.287 | 3.229 | 1.69 | 0.059 | N |
| | | Historical | Baseline | 511.2 | 292.2 | 31.9 | 8203.4 | 614.5 | 449.7 | 1.299 | 0.311 | 2.081 | 1.122 | 0.13 | N |
| | | | Current Ops | 610.3 | 334.4 | 33.4 | 11141 | 754 | 533.6 | 1.355 | 0.323 | 2.386 | 1.372 | 0.106 | N |
| | | | Projected BiOp | 662.2 | 355.6 | 34.5 | 12703.6 | 831.5 | 578 | 1.383 | 0.327 | 2.552 | 1.498 | 0.094 | N |
| | | | 100% Survival | 1364.4 | 643.8 | 47.5 | 39180 | 2043.8 | 1263 | 1.727 | 0.374 | 5.208 | 3.706 | 0.026 | Y |
| | South Fork Salmon River | Warm PDO | Baseline | 599.4 | 178.7 | 117.5 | 3058.5 | 613.5 | 185.8 | 0.775 | 0.116 | 0.929 | 0.221 | 0 | N |
| | | | Current Ops | 719.1 | 207 | 136.3 | 3792.4 | 720.9 | 220.4 | 0.813 | 0.121 | 1.037 | 0.275 | 0 | N |
| | | | Projected BiOp | 783.3 | 219.5 | 148 | 4146.1 | 781.6 | 240.8 | 0.834 | 0.123 | 1.097 | 0.309 | 0 | N |
| | | | 100% Survival | 1611.5 | 339.6 | 304.5 | 8529.6 | 1784.5 | 486.5 | 1.088 | 0.138 | 2.199 | 0.994 | 0 | Y |
| | | Baseline | Baseline | 755.2 | 208.3 | 142.2 | 4011.4 | 767.5 | 229.8 | 0.843 | 0.134 | 1.104 | 0.327 | 0 | N |
| | | | Current Ops | 896 | 238.9 | 162.4 | 4944.1 | 902.4 | 278.1 | 0.881 | 0.14 | 1.248 | 0.43 | 0 | N |
| | | | Projected BiOp | 972.7 | 252.6 | 174.2 | 5431.6 | 979.6 | 303.7 | 0.902 | 0.142 | 1.327 | 0.479 | 0 | N |
| | | | 100% Survival | 1972.7 | 387 | 317.3 | 12265 | 2165.6 | 560.7 | 1.142 | 0.16 | 2.772 | 1.69 | 0 | Y |
| | | Historical | Baseline | 1400.1 | 569.2 | 258.1 | 7595.1 | 1432.1 | 666.4 | 0.939 | 0.198 | 1.662 | 1.113 | 0 | Y |
| | | | Current Ops | 1625.5 | 644.3 | 281.7 | 9380.2 | 1678.6 | 785.3 | 0.97 | 0.204 | 1.912 | 1.393 | 0 | Y |
| | | | Projected BiOp | 1747.2 | 678.6 | 296.7 | 10288.8 | 1817.2 | 844.1 | 0.989 | 0.206 | 2.062 | 1.582 | 0 | Y |
| | | | 100% Survival | 3247.8 | 1145.5 | 490.5 | 21504.9 | 3804.9 | 1625.2 | 1.218 | 0.228 | 4.146 | 3.279 | 0 | Y |

Table 7 c: 25 year model runs, continued.

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **ESU** | **Population** | **Climate scenario** | **Hydropower system scenario** | **Mean** | **Standard deviation (across simulations)** | **Lower confidence limit** | **Upper confidence limit** | **Median** | **Standard deviation** | **Mean R/S at all densities** | **Standard deviation of R/S at all densities** | **Mean R/S at low densities** | **Standard deviation of R/S at low densities** | **Probability of quasi extinction** | **Viability** |
| Snake River Spring/Summer Chinook | Marsh Creek | Warm PDO | Baseline | 103.1 | 48 | 13.5 | 787.5 | 102.9 | 54.3 | 0.81 | 0.154 | 0.943 | 0.274 | 0.53 | N |
| | | | Current Ops | 127.5 | 57 | 15.5 | 1051.2 | 128 | 68.8 | 0.863 | 0.161 | 1.063 | 0.343 | 0.422 | N |
| | | | Projected BiOp | 141.3 | 61.3 | 16.7 | 1195.1 | 142.8 | 76 | 0.893 | 0.165 | 1.132 | 0.379 | 0.366 | N |
| | | | 100% Survival | 327.7 | 106.8 | 30.9 | 3478.8 | 388.2 | 168 | 1.237 | 0.197 | 2.306 | 1.172 | 0.098 | N |
| | | Baseline | Baseline | 137 | 59.3 | 16.7 | 1120.4 | 139.6 | 72.9 | 0.9 | 0.172 | 1.131 | 0.394 | 0.419 | N |
| | | | Current Ops | 167.2 | 68.9 | 18.8 | 1485.3 | 173 | 89.4 | 0.956 | 0.181 | 1.287 | 0.502 | 0.33 | N |
| | | | Projected BiOp | 184 | 73.9 | 20.1 | 1683.3 | 192.3 | 98.2 | 0.985 | 0.185 | 1.379 | 0.567 | 0.287 | N |
| | | | 100% Survival | 415.3 | 124.7 | 33.5 | 5153.3 | 497.8 | 200.5 | 1.306 | 0.219 | 2.917 | 1.921 | 0.074 | N |
| | | Historical | Baseline | 285.9 | 150.4 | 30.3 | 2698.2 | 312.1 | 199.9 | 1.049 | 0.25 | 1.79 | 1.143 | 0.189 | N |
| | | | Current Ops | 338.3 | 170.6 | 32.6 | 3512.1 | 377.4 | 235.2 | 1.096 | 0.258 | 2.064 | 1.4 | 0.149 | N |
| | | | Projected BiOp | 366.5 | 181 | 34.2 | 3931.1 | 413.9 | 253.4 | 1.122 | 0.261 | 2.211 | 1.543 | 0.129 | N |
| | | | 100% Survival | 726.9 | 313 | 51.9 | 10180.9 | 962.2 | 523.4 | 1.422 | 0.293 | 4.532 | 3.508 | 0.032 | Y |
| Upper Columbia River Spring Chinook | Wenatchee River | Warm PDO | Baseline | 239 | 105.8 | 31.3 | 1827.6 | 264.6 | 135.9 | 0.526 | 0.079 | 0.568 | 0.14 | 0.191 | N |
| | | | Current Ops | 347.1 | 145.5 | 59.3 | 2032.5 | 379.6 | 171.1 | 0.607 | 0.089 | 0.698 | 0.237 | 0.033 | N |
| | | | Projected BiOp | 415 | 168 | 78.4 | 2197.3 | 448.5 | 188.1 | 0.651 | 0.094 | 0.787 | 0.343 | 0.009 | N |
| | | | 100% Survival | 1194.9 | 384.2 | 239.7 | 5957.3 | 1201.4 | 446.2 | 0.949 | 0.127 | 2.29 | 2.407 | 0 | N |
| | | Baseline | Baseline | 326.3 | 138.2 | 42.7 | 2490.9 | 377.7 | 172.4 | 0.568 | 0.095 | 0.642 | 0.21 | 0.043 | N |
| | | | Current Ops | 465.6 | 184.7 | 73.3 | 2959 | 522.6 | 209.7 | 0.652 | 0.107 | 0.811 | 0.401 | 0.004 | N |
| | | | Projected BiOp | 550.9 | 208.7 | 91.8 | 3304.1 | 605.3 | 227.2 | 0.696 | 0.113 | 0.932 | 0.547 | 0.001 | N |
| | | | 100% Survival | 1475.3 | 438.9 | 233.1 | 9338.9 | 1508.7 | 542.5 | 0.983 | 0.154 | 2.97 | 2.707 | 0 | N |
| | | Historical | Baseline | 932.3 | 621.1 | 145.5 | 5971.7 | 908.8 | 582.4 | 0.727 | 0.157 | 1.103 | 1.02 | 0.014 | N |
| | | | Current Ops | 1241.9 | 774.1 | 202.9 | 7600.1 | 1209.3 | 765.4 | 0.809 | 0.165 | 1.34 | 1.302 | 0.001 | N |
| | | | Projected BiOp | 1430.5 | 860.1 | 233.6 | 8760.9 | 1394 | 873.7 | 0.85 | 0.169 | 1.46 | 1.429 | 0 | N |
| | | | 100% Survival | 3180.4 | 1554.4 | 409 | 24731.8 | 3327 | 1879.3 | 1.101 | 0.198 | 2.412 | 2.772 | 0 | Y |
| Mid-Columbia River Steelhead | Umatilla River | Warm PDO | Baseline | 1397.4 | 225.1 | 335.5 | 5820.9 | 1427.9 | 297.4 | 0.762 | 0.084 | 0.933 | 0.166 | 0 | N |
| | | | Current Ops | 1476 | 234.6 | 363 | 6002.1 | 1515.2 | 311.3 | 0.773 | 0.084 | 0.956 | 0.171 | 0 | N |
| | | | Projected BiOp | 1634 | 255.2 | 417.5 | 6395.4 | 1688.5 | 337.5 | 0.793 | 0.085 | 1.003 | 0.185 | 0 | N |
| | | | 100% survival | 2239.4 | 333 | 626.3 | 8007.7 | 2335.1 | 435 | 0.857 | 0.089 | 1.194 | 0.245 | 0 | Y |
| | | Baseline | Baseline | 1495.1 | 234.7 | 356.3 | 6273.1 | 1557.7 | 317.4 | 0.77 | 0.093 | 0.97 | 0.188 | 0 | N |
| | | | Current Ops | 1579.3 | 246.1 | 384.4 | 6489.1 | 1652.9 | 332.6 | 0.782 | 0.094 | 0.997 | 0.197 | 0 | N |
| | | | Projected BiOp | 1746 | 265.6 | 440.1 | 6927 | 1839 | 359.4 | 0.801 | 0.095 | 1.051 | 0.215 | 0 | N |
| | | | 100% survival | 2391 | 343.7 | 655.8 | 8716.5 | 2536.8 | 451.2 | 0.865 | 0.101 | 1.283 | 0.304 | 0 | Y |
| | | Historical | Baseline | 1712 | 405.3 | 366 | 8008 | 1738.3 | 451.6 | 0.77 | 0.106 | 1.111 | 0.312 | 0 | N |
| | | | Current Ops | 1807 | 422.3 | 393.9 | 8288.4 | 1841.6 | 468.9 | 0.781 | 0.107 | 1.148 | 0.327 | 0 | N |
| | | | Projected BiOp | 1995 | 460.7 | 448.1 | 8881.1 | 2041.8 | 509.4 | 0.8 | 0.109 | 1.223 | 0.359 | 0 | Y |
| | | | 100% survival | 2723.7 | 605.3 | 655.1 | 11324.3 | 2771.4 | 615.2 | 0.863 | 0.116 | 1.528 | 0.508 | 0 | Y |

Table 7 c: 25 year model runs, continued.

| | | | | Mean spawners | | | | Median spawners | | Productivity | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ESU | Population | Climate scenario | Hydropower system scenario | Mean | Standard deviation (across simulations) | Lower confidence limit | Upper confidence limit | Median | Standard deviation | Mean R/S at all densities | Standard deviation of R/S at all densities | Mean R/S at low densities | Standard deviation of R/S at low densities | Probability of quasi extinction | Viability |
| Snake River Steelhead | Little Salmon River | Warm PDO | Baseline | 68.7 | 11 | 19.9 | 236.9 | 71.1 | 13.2 | 0.911 | 0.115 | 1.536 | 0.441 | 0.929 | N |
| | | | Current Ops | 66.6 | 10.7 | 19.4 | 229 | 69 | 13 | 0.902 | 0.114 | 1.486 | 0.414 | 0.945 | N |
| | | | Projected BiOp | 61.3 | 9.9 | 17.7 | 212.3 | 63.7 | 12.4 | 0.877 | 0.111 | 1.376 | 0.363 | 0.975 | N |
| | | | 100% survival | 89.3 | 14.1 | 25.9 | 308.2 | 89.6 | 15.4 | 0.999 | 0.125 | 1.986 | 0.704 | 0.648 | N |
| | | Baseline | Baseline | 70.8 | 11.2 | 19.8 | 253.3 | 72.9 | 13.4 | 0.916 | 0.129 | 1.562 | 0.471 | 0.928 | N |
| | | | Current Ops | 68.6 | 10.9 | 19.2 | 245 | 70.8 | 13.2 | 0.907 | 0.128 | 1.516 | 0.446 | 0.943 | N |
| | | | Projected BiOp | 63.2 | 10.1 | 17.6 | 227 | 65.4 | 12.6 | 0.882 | 0.125 | 1.406 | 0.391 | 0.974 | N |
| | | | 100% survival | 92 | 14.3 | 26.3 | 321.8 | 92.3 | 15.6 | 1.004 | 0.136 | 2.024 | 0.749 | 0.628 | N |
| | | Historical | Baseline | 116.9 | 35.7 | 31.6 | 431.7 | 117.3 | 37.5 | 0.979 | 0.216 | 2.093 | 1.378 | 0.444 | N |
| | | | Current Ops | 113.3 | 34.7 | 30.8 | 417.3 | 113.8 | 36.2 | 0.972 | 0.213 | 2.053 | 1.318 | 0.46 | N |
| | | | Projected BiOp | 104.5 | 32.1 | 28.5 | 383.4 | 105.2 | 33.3 | 0.945 | 0.209 | 1.912 | 1.149 | 0.507 | N |
| | | | 100% survival | 149.5 | 44.7 | 39.3 | 569.3 | 149.5 | 50.4 | 1.066 | 0.229 | 2.535 | 2.052 | 0.264 | N |

Table 8. Analysis of Variance evaluating the effect of climate scenario, hydro scenario and ESU on productivity (R/S) at low densities.

| **Source** | **Sum-of-Squares** | **df** | **Mean-Square** | **F-ratio** | **p** |
|---|---|---|---|---|---|
| ESU | 2.354 | 3 | 0.785 | 26.893 | 0.000 |
| CLIMATE | 2.334 | 2 | 1.167 | 40.000 | 0.000 |
| HYDRO | 12.993 | 3 | 4.331 | 148.442 | 0.000 |
| CLIMATE * ESU | 0.625 | 6 | 0.104 | 3.568 | 0.007 |
| CLIMATE * HYDRO | 0.716 | 6 | 0.119 | 4.089 | 0.003 |
| HYDRO * ESU | 6.112 | 9 | 0.679 | 23.275 | 0.000 |
| HYDRO * CLIMATE * ESU | 0.586 | 18 | 0.033 | 1.116 | 0.377 |
| Error | 1.050 | 36 | 0.029 | | |

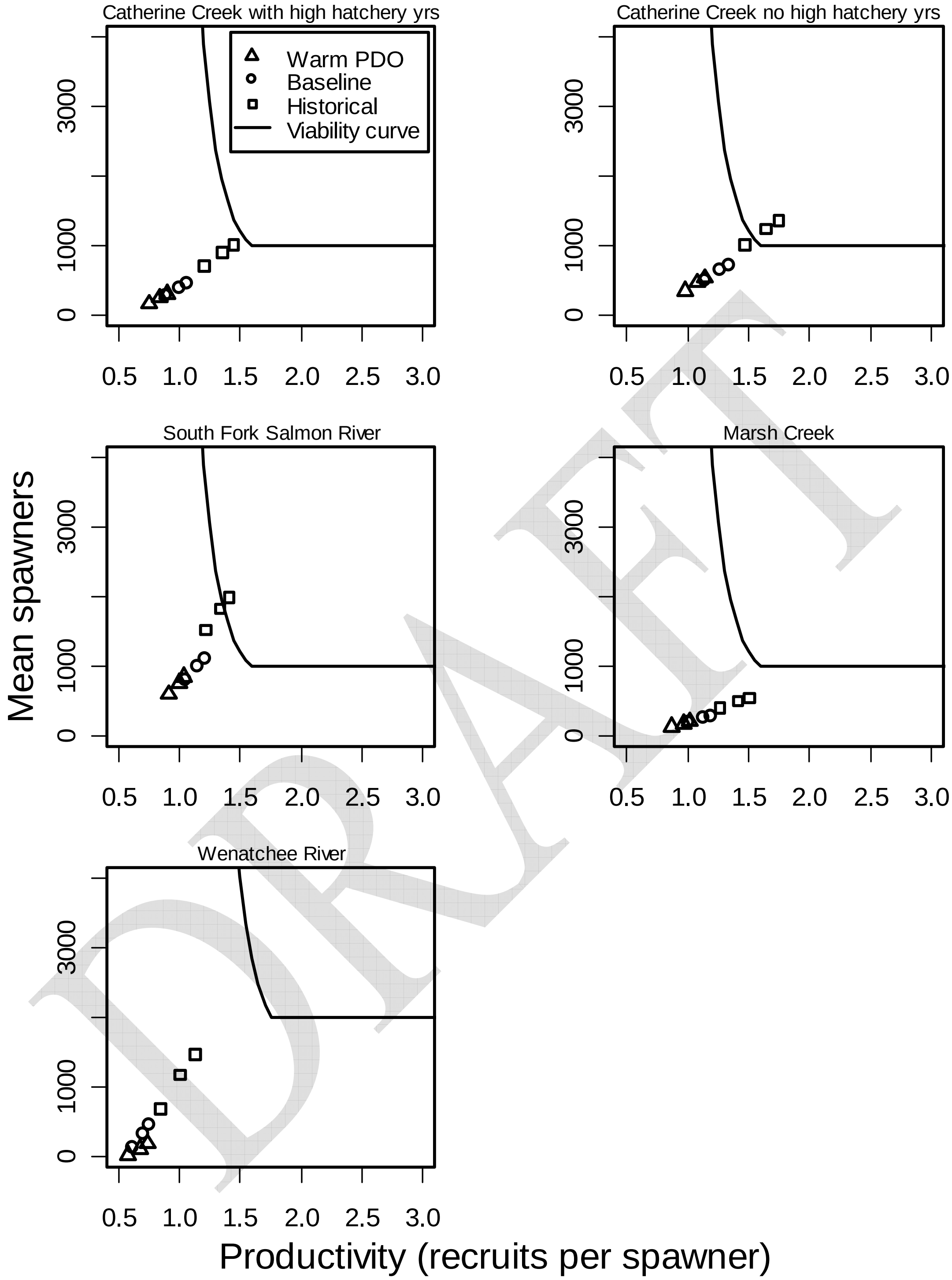


Figure 6a: Mean spawners and productivity (recruits per spawner) for Chinook salmon populations under three climate scenarios (warm PDO, triangles; baseline, circles; historical, squares), with the viability curves (solid lines) superimposed. Populations are Catherine Creek with and without high hatchery contribution years, South Fork Salmon River, Marsh Creek (all part of Snake River Spring/Summer Chinook ESU), and Wenatchee River (Upper Columbia River Spring Chinook ESU).

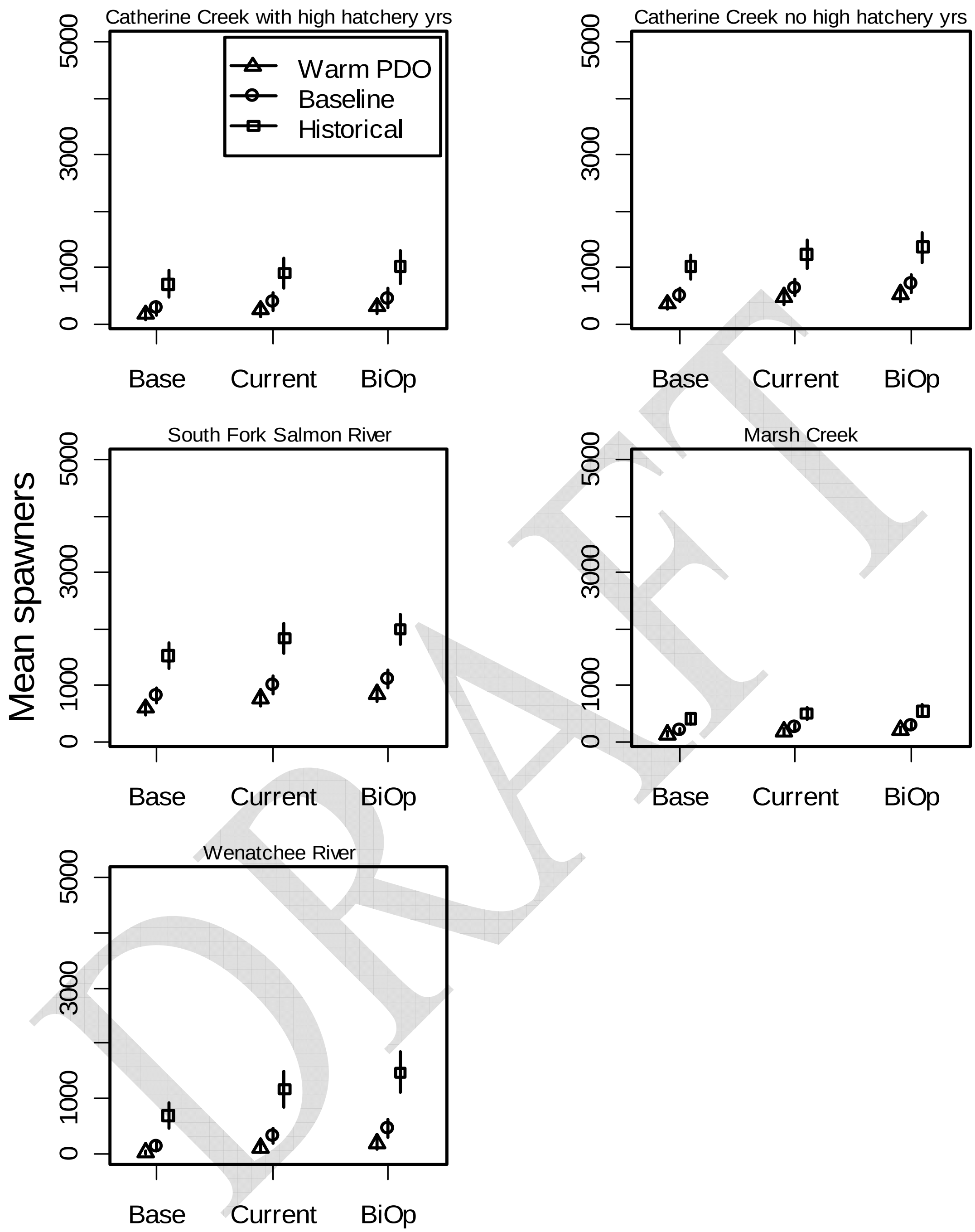


Figure 6b: Mean spawners under three hydropower scenarios ("Base", "Current", and "BiOp") and three climate scenarios (warm PDO, triangles; baseline, circles; historical, squares), with bars marking ± 1 standard deviation. Populations are Catherine Creek with and without high hatchery contribution years, South Fork Salmon River, Marsh Creek (all part of Snake River Spring/Summer Chinook ESU), and Wenatchee River (Upper Columbia River Spring Chinook ESU).

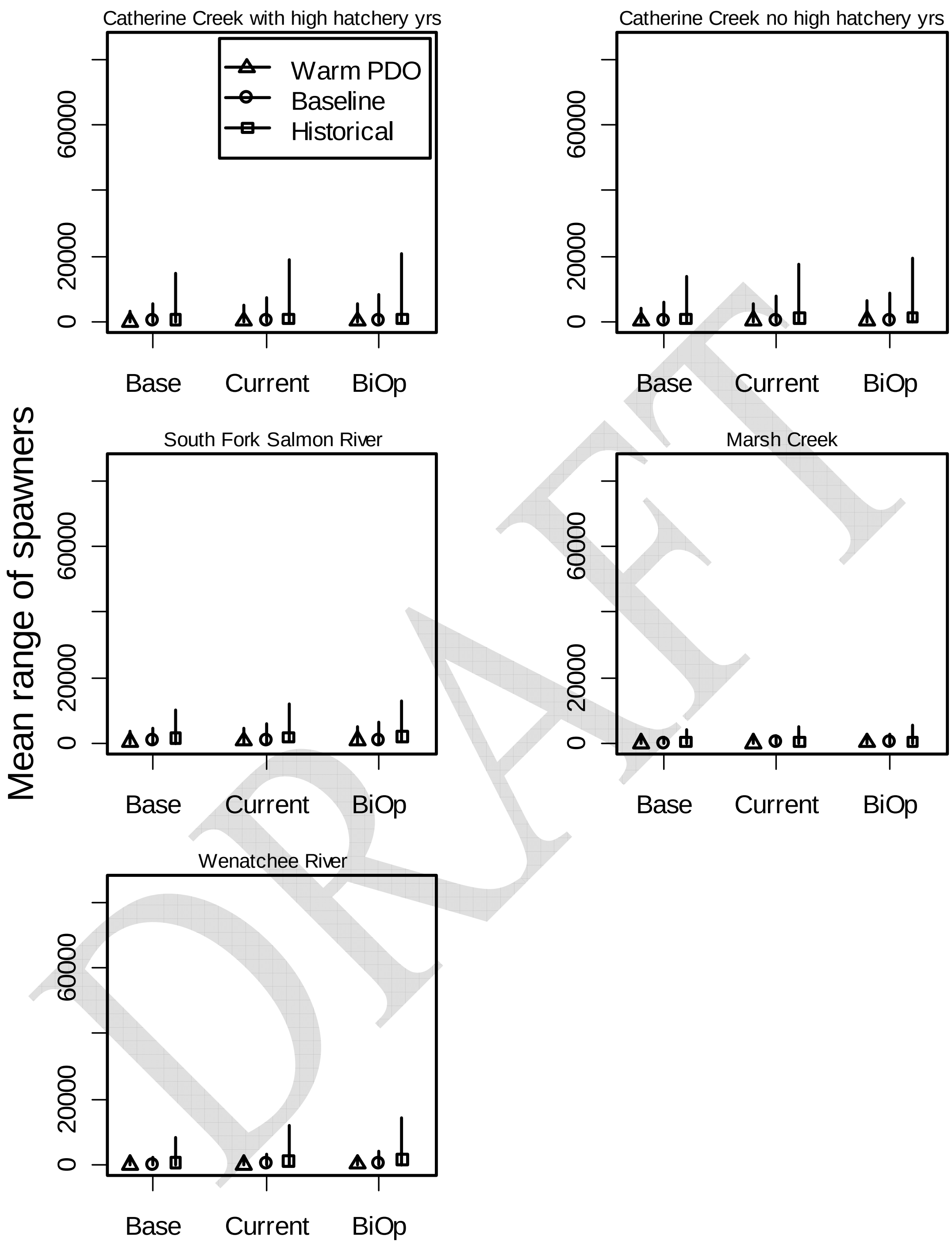


Figure 6c: Mean range of spawners under three hydropower scenarios ("Base", "Current", and "BiOp") with the mean of the ranges denoted by symbols, and three climate scenarios (warm PDO, triangles; baseline, circles; historical, squares). Populations are Catherine Creek with and without high hatchery contribution years, South Fork Salmon River, Marsh Creek (all part of Snake River Spring/Summer Chinook ESU), and Wenatchee River (Upper Columbia River Spring Chinook ESU).

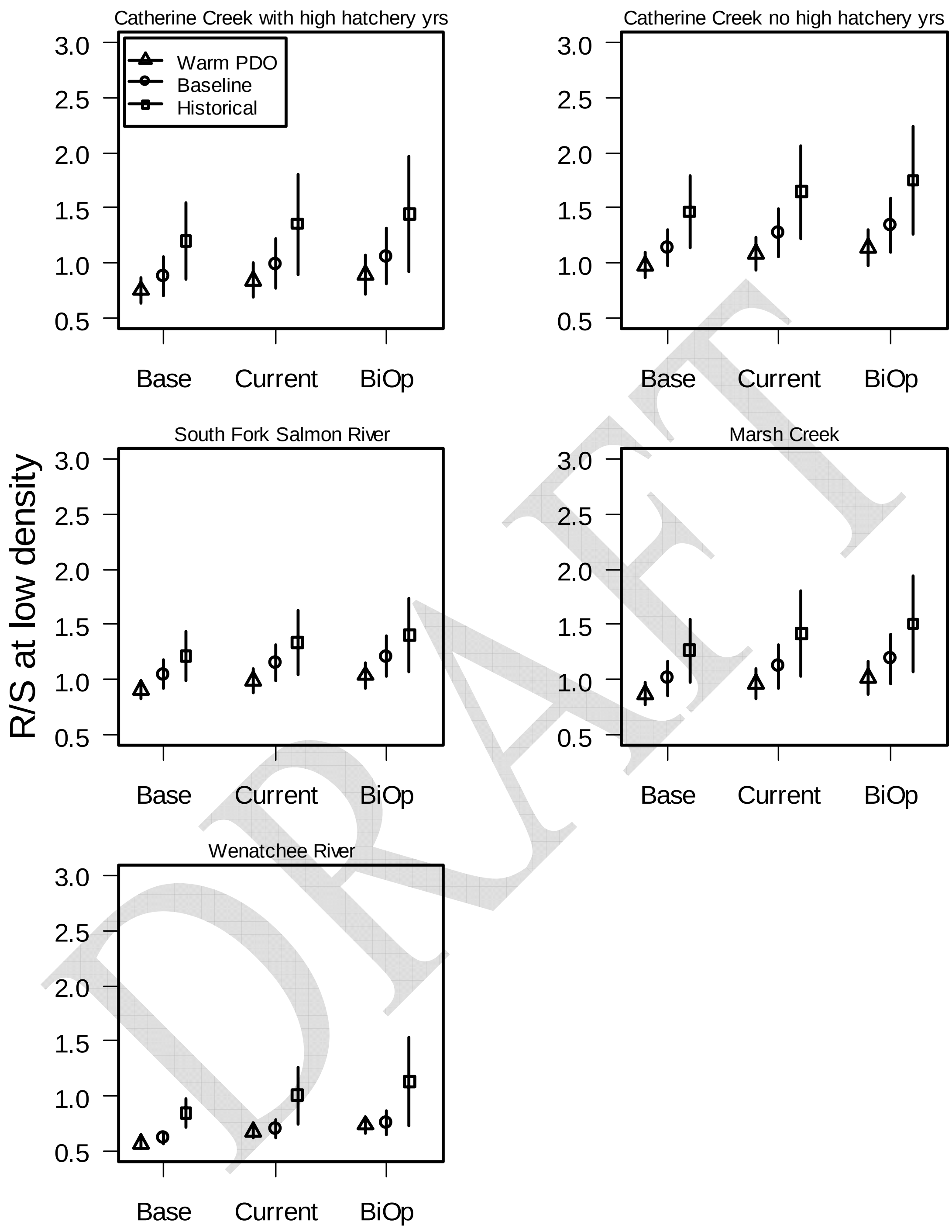


Figure 6d: Recruits per spawner at low spawner densities under three hydropower scenarios (“Base”, “Current”, and “BiOp”), and three climate scenarios (warm PDO, triangles; baseline, circles; historical, squares). Lines depict ± 1 standard deviation. Populations are Catherine Creek with and without high hatchery contribution years, South Fork Salmon River, Marsh Creek (all part of Snake River Spring/Summer Chinook ESU), and Wenatchee River (Upper Columbia River Spring Chinook ESU).

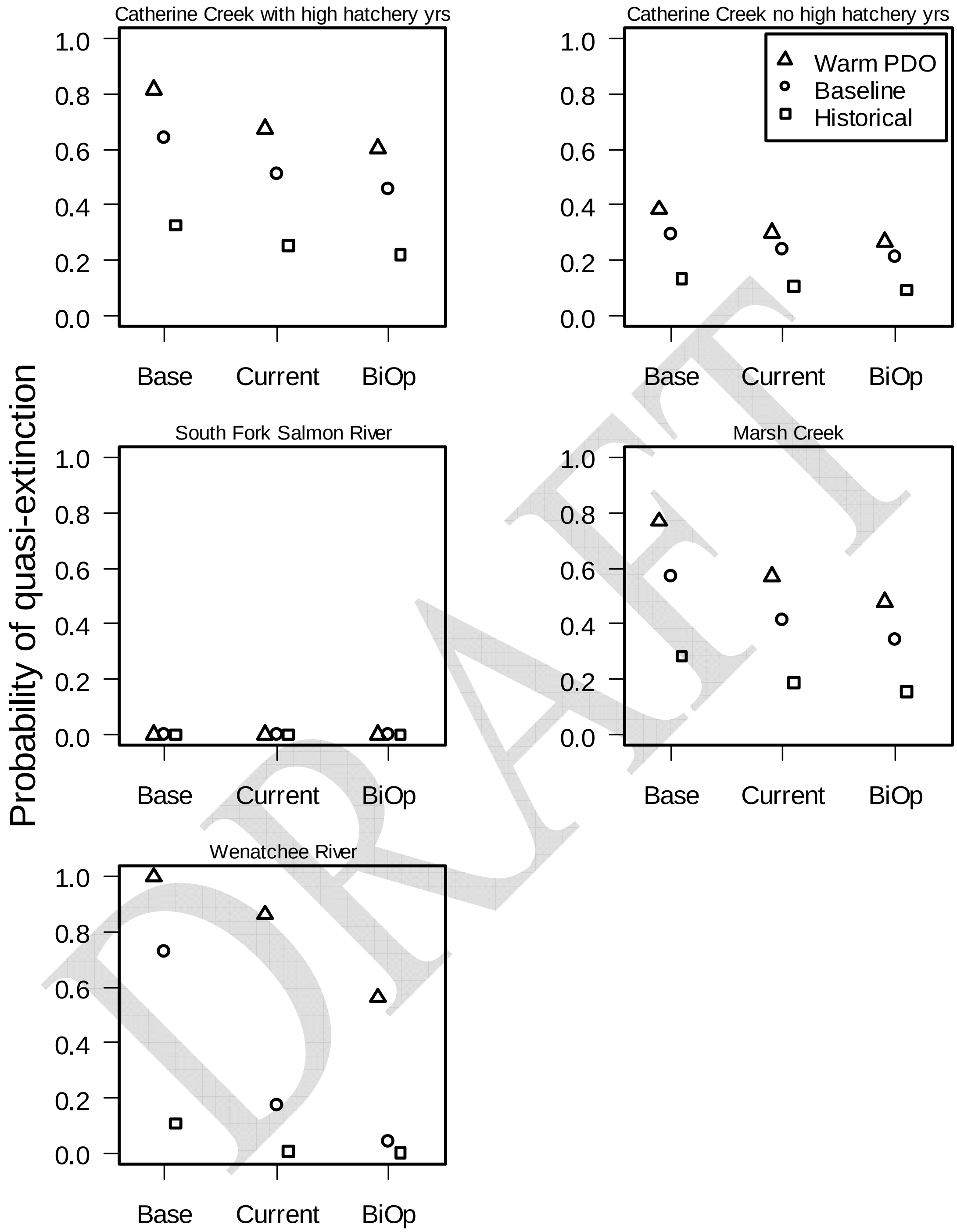


Figure 6e: Probability of quasi-extinction under three hydropower scenarios ("Base", "Current", and "BiOp"), and three climate scenarios (warm PDO, triangles; baseline, circles; historical, squares). Populations are Catherine Creek with and without high hatchery contribution years, South Fork Salmon River, Marsh Creek (all part of Snake River Spring/Summer Chinook ESU), and Wenatchee River (Upper Columbia River Spring Chinook ESU).

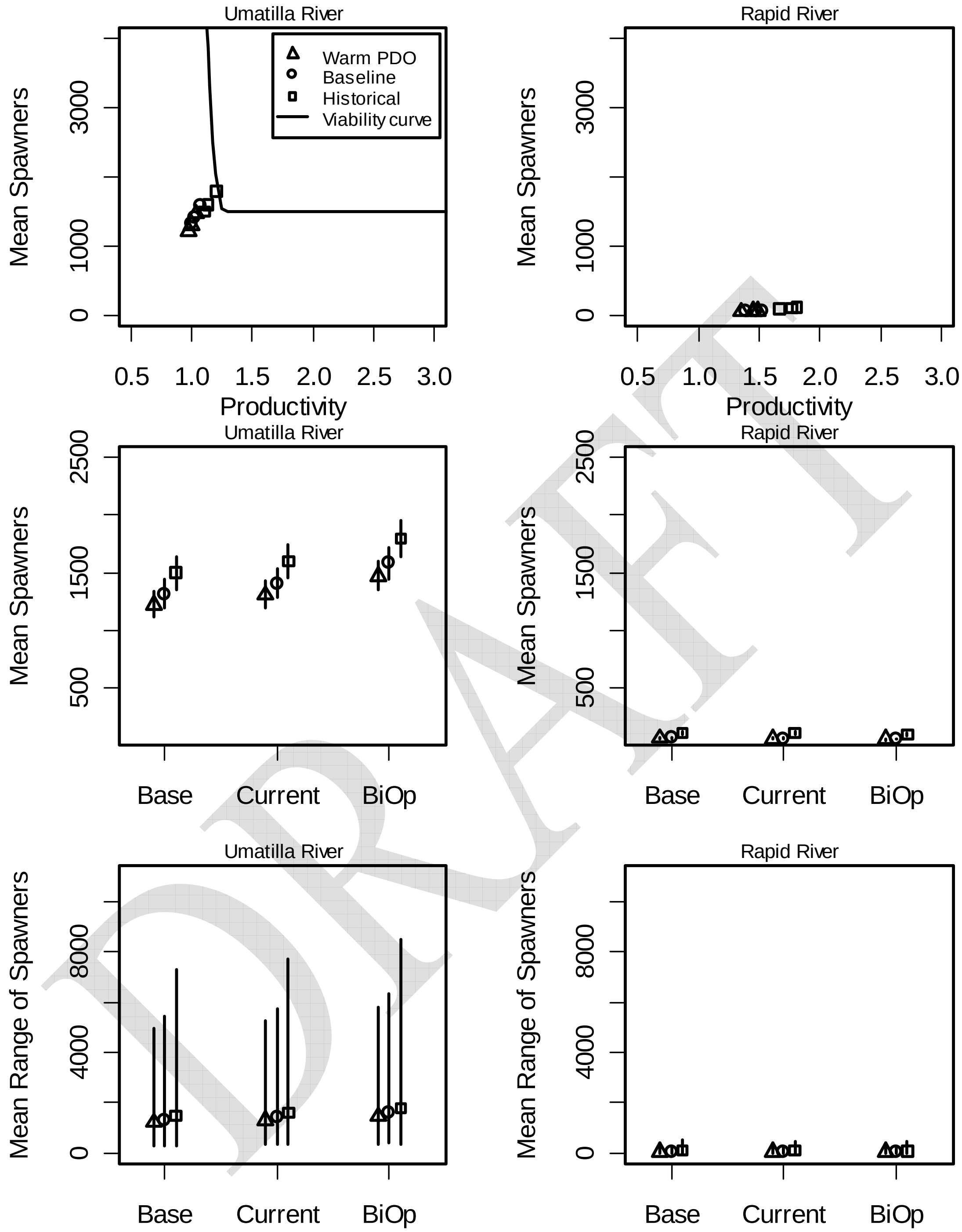


Figure 7a: Model results for two populations of steelhead, Umatilla River (left column) and Rapid River (right column), under three climate scenarios (warm PDO, triangles; baseline, circles; historical, squares), and three hydropower operation scenarios ("Base", "Current", and "BiOp"). The plots include results from model runs for 25, 50, and 100 years. The first row contains plots of the mean number of spawners versus productivity (as measured by recruits per spawner) with the viability curve associated with Umatilla River population. The second row contains plots of the mean number of spawners, with lines marking ± 1 standard deviation. The third row contains plots of the mean number of spawners with their ranges represented by the solid lines.

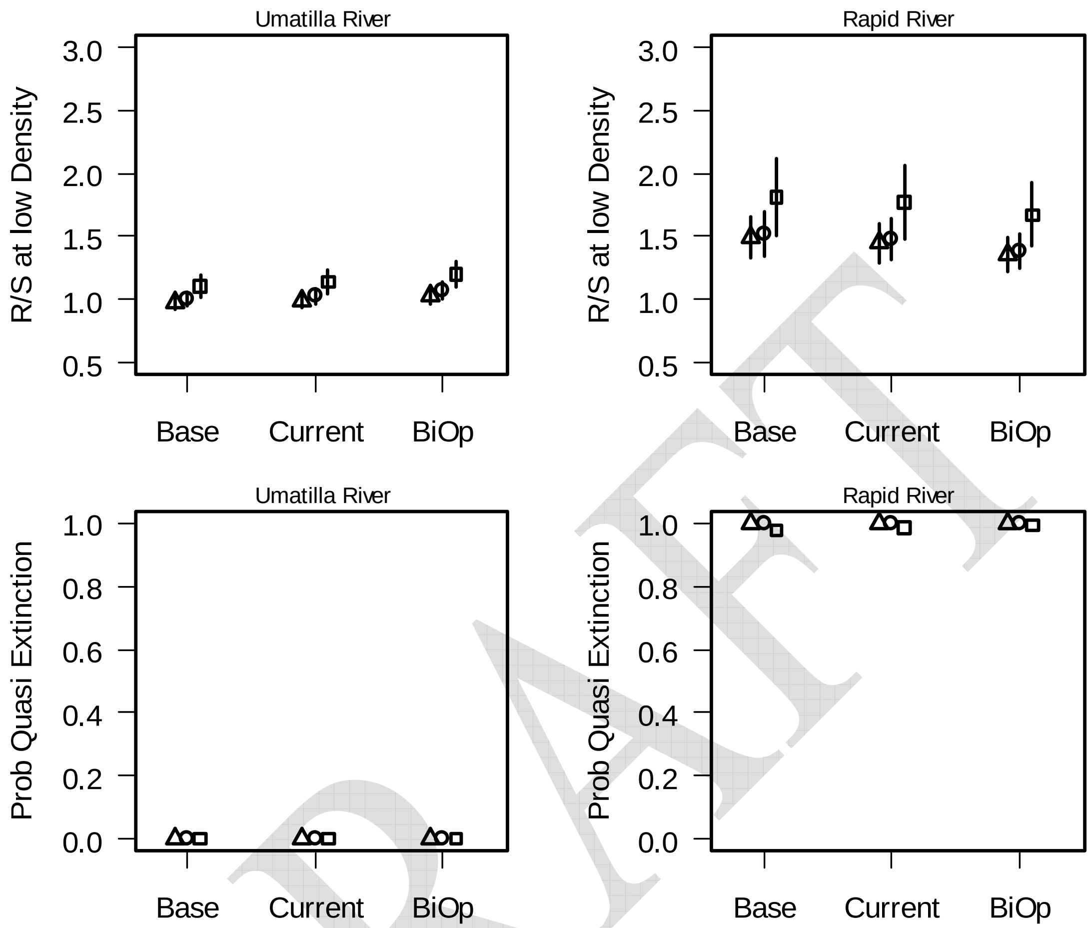


Figure 7b: Model results for two populations of steelhead, Umatilla River (left column) and Rapid River (right column), under three climate scenarios (warm PDO, triangles; baseline, circles; historical, squares), and three hydropower operation scenarios ("Base", "Current", and "BiOp"). The first row of plots shows the recruits per spawner at low spawner densities, with lines indicating ± 1 standard deviation. The second row of plots depicts the probability of quasi-extinction.

## 1. Hydropower Scenarios

When all scenarios are considered, the significant effect of hydropower scenarios is driven by the dramatic increase of productivity under the hypothetical "100% hydrosystem survival" scenario (Figure 8). In addition, there was also a significant interaction between hydropower scenarios and ESU under the modeled parameters (Table 8). Specifically, Snake River Steelhead showed a negative response to the Current Operation and the Projected BiOp scenarios, while the other ESUs responded positively. In addition, Chinook salmon ESUs responded more dramatically to the 100% Survival scenario (in the hydropower system) than did steelhead ESUs (Figure 9). This suggests that ESU-specific, and possibly population-specific responses to changes in the hydropower system will be important to track and to account for in recovery planning efforts. Operations that may be sufficient or positive for one ESU/population may be neutral or even negative for others.

When ESUs are analyzed individually and without the hypothetical 100% Survival scenario (which inflates the model error when it is included), all ESUs show significant differences in productivity between the Baseline scenario and the survival under the Projected BiOp scenario, and all but Upper Columbia spring Chinook salmon also have significantly different productivities between the Baseline and Current Operations scenarios (Table 9). This suggests that the recent and proposed future changes to the hydropower system affecting in-river survival can have somewhat small (in comparison with environmental scenarios), but significant effects on population productivity. In addition, for Snake River spring/summer Chinook salmon, the difference between Baseline and Current Operations is larger than the difference between Current Operations and the Projected BiOp. This indicates that past actions have been important for this ESU, but that the direct survival improvements projected for the proposed changes to the hydrosystem operation are unlikely to bring the same magnitude of change.

Under the hypothetical “100% Survival” scenario, in which no fish die during the juvenile migration, the productivity of all populations is increased substantially – from 24% (Snake River steelhead) to 327% (Upper Columbia spring Chinook salmon). All populations except the Little Salmon River steelhead had median spawner numbers and intrinsic productivities consistent with viability criteria under all environmental scenarios in this extreme case (Tables 7a-c). [Note that the Little Salmon River steelhead model was developed for a subsection of the population; this result may change as its model is refined.] Importantly, the amount by which viability criteria are exceeded varies considerably among the individual populations due to the combination of the population’s current status and the projected change for the ESU. In some cases the resulting levels under this scenario exceed the required level of change by a considerable amount. For example, the 100% Survival scenario leads to the South Fork Salmon River population (Snake River spring/summer Chinook ESU) to surpass viability criteria by a very large amount. In fact, a relatively small increase in productivity and abundance over the model outputs for the Current Operations scenario would exceed the ICTRT viability curve for this population. Other populations, such as the Marsh Creek population, only scarcely exceed viability criteria levels when 100% Survival through the hydropower system is assumed[3]. The results from this "thought experiment" do indicate that large improvements in survival through the hydropower corridor – well above those envisioned in current proposals -- could make a substantial difference for the status of at least some of these populations/ESUs.

Figure 8

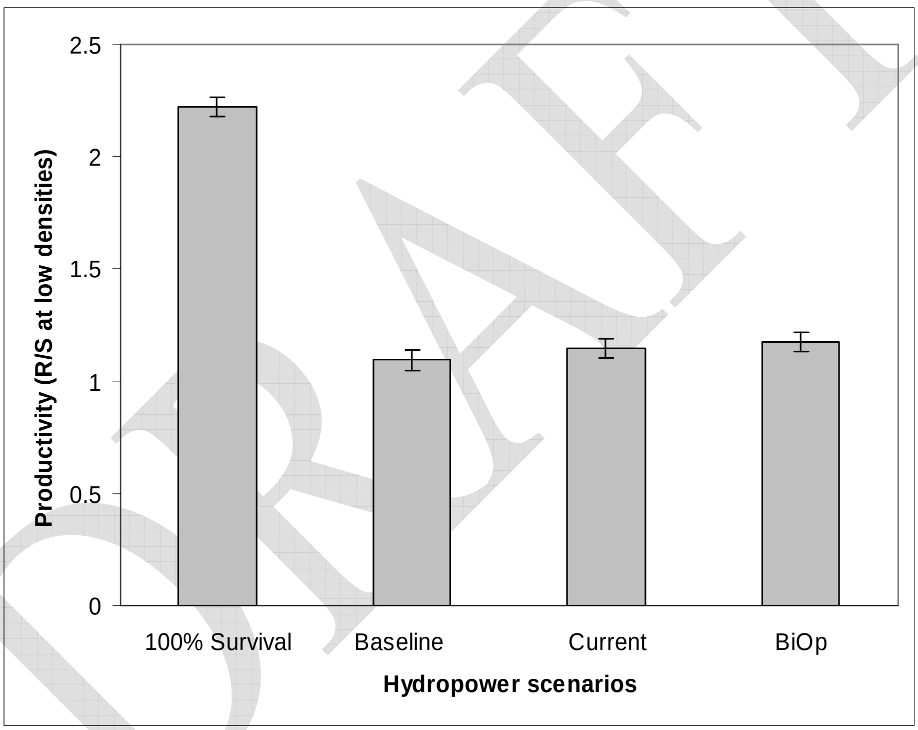


Figure 8: Recruits per spawner at low spawner densities across all ESUs under three hydropower scenarios, and under a hypothetical assumption of 100% survival through the hydropower system. Error bars mark one standard error.

[3] Again, 100% survival through the hydropower system is not attainable, and this exercise does not include any potential latent mortality outside the migration corridor. Also note that a 100% transportation scenario would include delayed differential mortality of transported fish and overall productivity would not approach the 100% survival scenario.

Figure 9

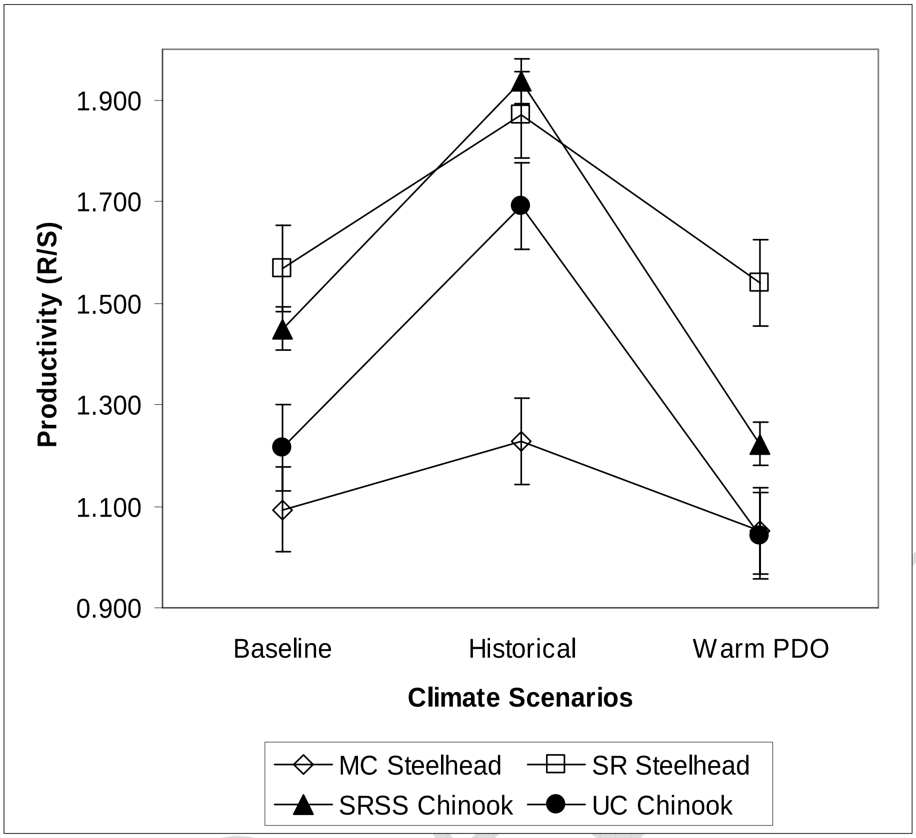


Figure 9: Recruits per spawner at low spawner densities by ESU under three climate scenarios, and under an assumption of 100% survival through the hydropower system. 100% survival through the hydropower system is a purely hypothetical and unattainable scenario. Data is included for Mid-Columbia River Steelhead ESU, Snake River Steelhad ESU, Snake River Spring/Summer Chinook ESU, and Upper Columbia River Spring Chinook ESU. Error bars mark ± 1 standard error.

Table 9. Absolute difference in productivity between baseline and current operations or baseline and projected BiOp survivals, calculated as a post-hoc pairwise comparison, using a Bonferroni correction.

| **ESU** | **df** | **Baseline-Current Ops Difference** | **Baseline-Current Ops Bonferroni p** | **Baseline-Projected BiOp Difference** | **Baseline-Projected BiOp Bonferroni p** |
|---|---|---|---|---|---|
| Snake River Spring / Summer Chinook | 27 | 0.119 | 0.061 | 0.188 | 0.002 |
| Upper Columbia River Spring Chinook | 4 | 0.115 | 0.061 | 0.195 | 0.010 |
| Snake River Steelhead | 4 | - 0.041 | 0.000 | -0.137 | 0.000 |
| Mid-Columbia River Steelhead | 4 | 0.024 | 0.099 | 0.074 | 0.002 |

Under the realistic hydropower scenarios -- Baseline, Current Operations and Projected BiOp scenarios – only two populations had modeled median spawner numbers and productivities consistent with viability criteria, but only under environmental conditions most favorable to the population (see below). The Catherine Creek (with high hatchery years excluded and the South Fork Salmon River populations (Snake River spring/summer chinook ESU) had abundance (median spawner number) and intrinsic productivities consistent with viability criteria under the projected BiOp improvements coupled with the Historical environmental scenario, but not with the Warm PDO or Baseline environmental scenarios. The Catherine Creek population also achieves viability criteria under the Current Operations hydropower scenarios, when coupled with the Historical environmental scenario. It should be noted that although the modeled abundance/productivity for Catherine Creek met or exceeded ICTRT 5% risk of extinction A/P criteria for some scenarios the model extinction risk was well above 5% in all cases. As described earlier, there are a variety of factors that can contribute to this result including the low abundance at the initiation of the matrix model runs. These model results suggest that additional improvements in hydrosystem survival and other life stages would be necessary for the remaining populations or under less favorable environmental conditions.

## 2. Environmental Scenarios

Environmental scenarios had a profound effect on population status. Across all ESUs, climate was a significant predictor of population productivity (Table 8, Figure 10). In general, cooler ocean/climate conditions like those seen historically were associated with higher estuary/early ocean survival rates for all ESUs. However, specific indicators were not uniform across ESUs. Higher estuary and ocean survival rates for Chinook salmon ESUs were associated with stronger nearshore upwelling conditions in the spring time period. In addition, as Water Travel Time (WTT) decreased for the Snake River and Upper Columbia populations, estuarine and early ocean survival increased. Mid-Columbia steelhead estuarine and early ocean survival rates were associated only with monthly PDO indices. Nonetheless, some of the important factors were consistent within steelhead as well: April and May PDO were significant factors for both steelhead populations.

When analyzed individually, all ESUs showed a highly significant difference in productivity between the environmental Baseline scenario and the Historical scenario; all but the Upper Columbia spring Chinook showed a significant difference between the Baseline and Warm PDO scenarios (Table 10). However, as with hydropower actions, there was a significant interaction between environmental scenarios and ESU. In this case, Mid-Columbia steelhead responded less strongly to the “Historical” climate scenario than did the other ESUs, although the general pattern of response was the same (Figure 11). This differential response may be real, but may also reflect the short time-series and consequent uncertainty in the relationship between environmental indicators and estuarine/early ocean survival for this ESU. The two steelhead ESUs responded proportionately less than the stream-type Chinook salmon ESUs responded to alternate climate regimes (Figure 11). Upper Columbia spring Chinook salmon appear to be especially affected, as this population's proportionate response to the Historical scenario was most pronounced.

Figure 10

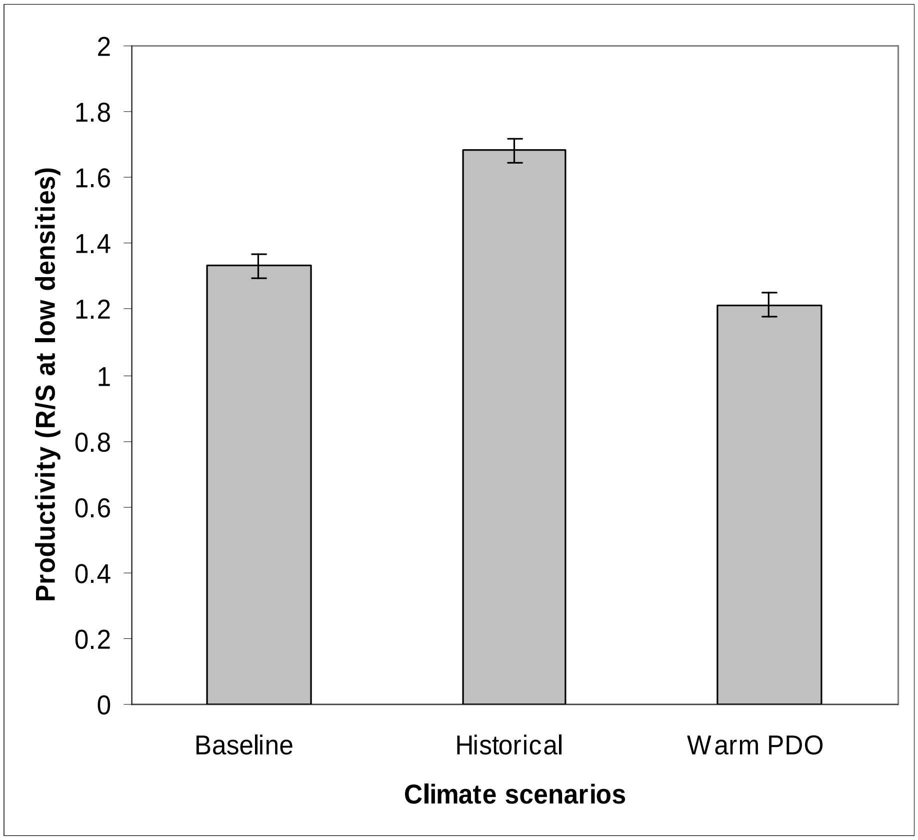


Figure 10: Recruits per spawner at low spawner densities across all ESUs under three climate scenarios. Error bars mark one standard error.

Figure 11

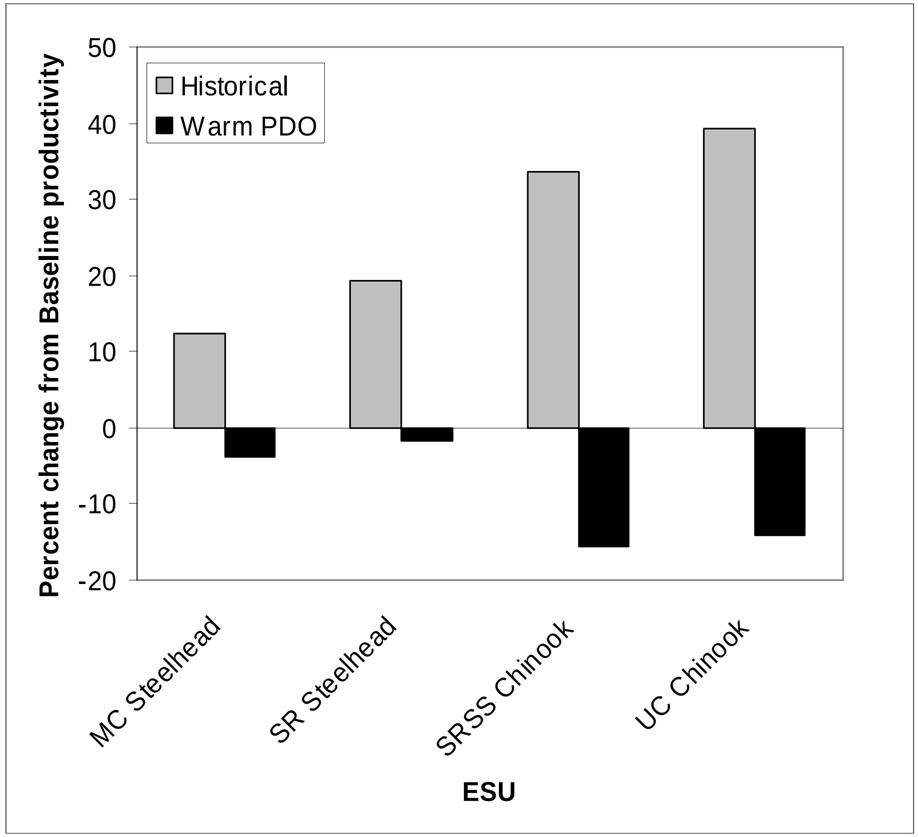


Figure 11: Recruits per spawner at low spawner densities by ESU under two climate scenarios, “Historical” (gray bars) and “Warm PDO” (black bars). ESUs include: Mid-Columbia River Steelhead ESU; Snake River Steelhad ESU; Snake River Spring/Summer Chinook ESU; and, Upper Columbia River Spring Chinook ESU.

Table 10. Absolute difference in productivity between baseline and modeled climate scenarios, calculated as a post-hoc pairwise comparison, using a Bonferroni correction.

| ESU | df | Baseline-Historical Difference | Baseline-Historical Bonferroni p | Baseline-Warm PDO Difference | Baseline-Warm PDO Bonferroni p |
|---|---|---|---|---|---|
| Snake River Spring / Summer Chinook | 27 | 0.299 | 0.000 | -0.162 | 0.007 |
| Upper Columbia River Spring Chinook | 4 | 0.304 | 0.002 | -0.029 | 1.000 |
| Snake River Steelhead | 4 | 0.290 | 0.000 | -0.030 | 0.000 |
| Mid-Columbia River Steelhead | 4 | 0.116 | 0.000 | -0.031 | 0.044 |

In addition, there was a significant interaction between climate and hydropower scenarios. Across all ESUs, there was a more pronounced response to hydropower scenarios under the historical climate regime than under the other two scenarios (Figure 12), indicating that the benefits of improvements to the hydropower system may be dependent in part on conditions outside that system.

Climate scenarios, by affecting productivity so strongly, clearly have the potential to affect viability. Among the set of realistic hydropower survival scenarios (Baseline, Current Operations and Projected BiOp), the only scenarios that achieved viability were those that included the Historical environmental scenario (Tables 7a-c). Those environmental scenarios include both ocean conditions (upwelling and temperature/PDO) and water travel time.

## 3. Catherine Creek

Among our analyzed populations, Catherine Creek was the most challenging to align modeled results with observed productivity. We modeled two scenarios for this population– one that excluded years with particularly high fraction of hatchery spawners, and one that included those years -- to bound the likely range of responses to climate and hydropower scenarios. Productivity in the scenarios that excluded hatchery fish was (not surprisingly) significantly higher than in those that did not (paired t-test, $t = 8.104$, $df = 11$, $p= 0.000$). However, the relative risk among the scenarios did not change.

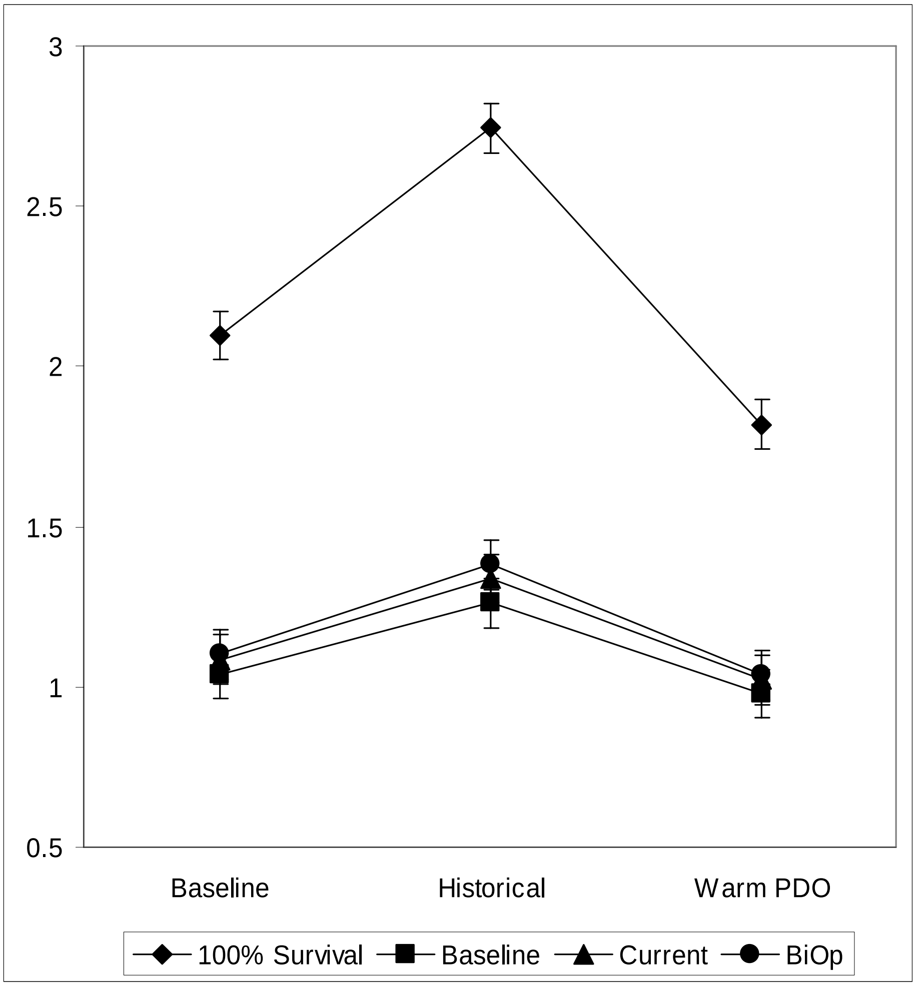


Figure 12: Response of populations to changes in hydropower operation scenarios under three different climate scenarios. Error bars represent ± 1 standard error. “100% Survival” through the hydropower system is a hypothetical, unattainable scenario, conducted as a mathematical experiment.

## 4. Time Frame for Evaluation

The period of time over which simulations were run also significantly affected the estimated productivity of modeled populations. Productivity measured after 25 years was significantly greater than that measured at 50 years (paired t-test, t= 6.394, df = 83, Bonferroni adjusted probability = 0.000), and that at 50 was significantly greater than productivity measured at 100 years (paired t-test, t=5.835, df=83, Bonferroni adjusted probability = 0.000). The average difference in productivity between the 25 year measure and the 100 year measure was 0.221. This effect occurred because in most cases, populations were growing; through time, freshwater productivity became increasingly dampened by density-dependent effects.

This effect was most pronounced for Snake River ESUs, and least significant in the Mid-Columbia steelhead and Upper Columbia spring Chinook salmon ESUs (Figure 13). In fact, some population-scenario combinations in the Umatilla and Wenatchee had productivities that were relatively constant across time periods or were greater when measured over the longer time period (Tables 7a-c). In general, the longer the time frame used in simulating a specific scenario combination for a population the greater the proportion of years in the run around the equilibrium abundance associated with the particular parameter set. This pattern in estimated productivities across different modeling time frames is consistent with the relative changes in mean and median estimates of abundances across the model runs. As noted above, the pattern for some scenario combinations for the Wenatchee and Umatilla population model runs did not follow this general tendency.  This may largely reflect an interplay between input starting population size and the effective equilibrium escapement level resulting from the combination of life stage survival and capacity input values.

Figure 13

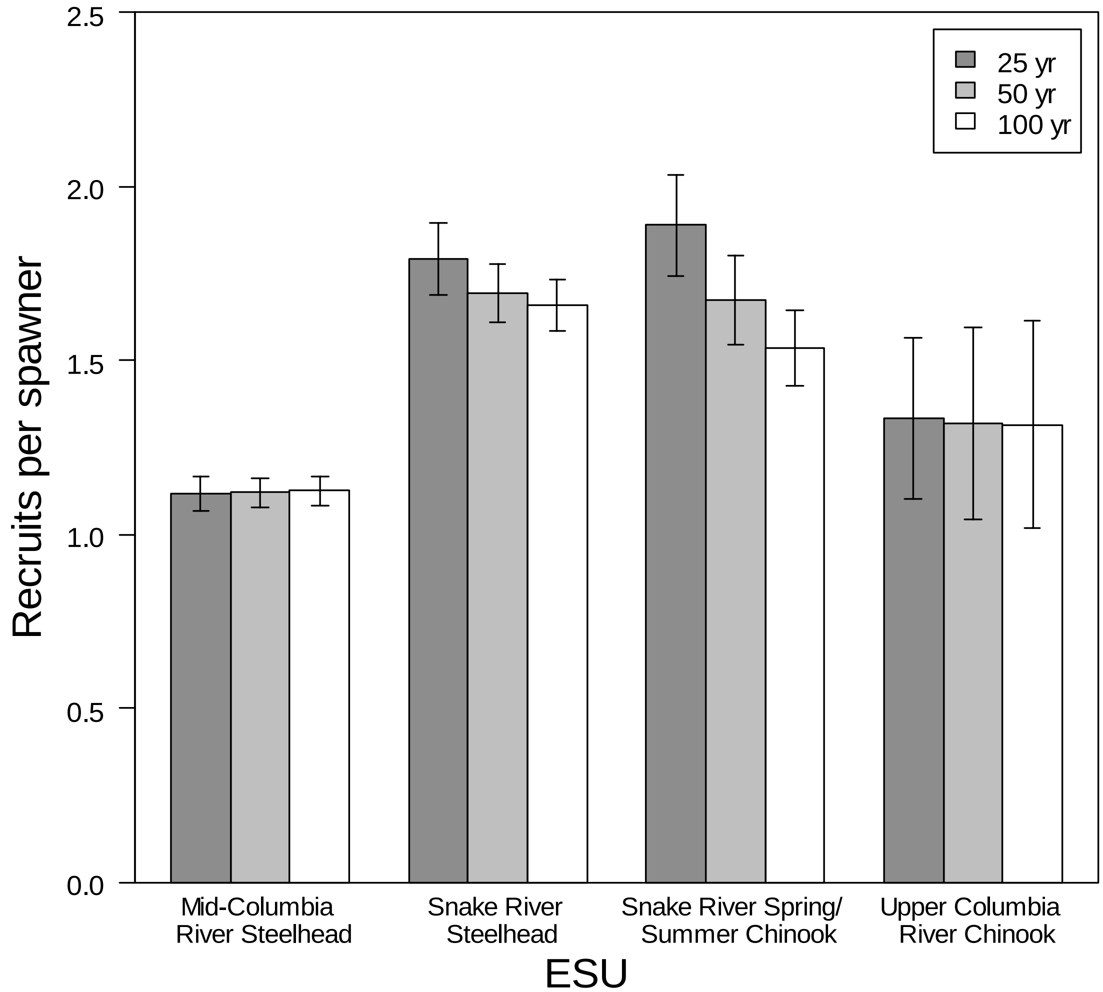


Figure 13: Recruits per spawner by ESU across three simulation model run times: 25 yr (left bars); 50 yr (middle bars); and, 100 yr (right bars). Error bars mark 1 standard error.

Overall, the relative status of most of the populations modeled in this study was similar to the findings described in our Current Status Assessments (Interior Columbia Technical Recovery Team 2007a). However, there were consistent differences in estimated population productivities and the absolute estimates of projected extinction risks. The probabilities of quasi-extinction developed in this model tended to be smaller than those developed with a hockey stick model in our status assessments, but the relative risk across populations was very similar (see accompanying report for further detail). The methods used for assessing risk in the ICTRT Current Status Assessments were designed weigh more recent estimates of productivity and abundance highly, and abundance and productivity estimated from the most recent 20 year data sets for each population were lower than estimates derived from longer time series.

## IV. Discussion

Our results indicate that environmental conditions, including both oceanic and freshwater components, have the potential to strongly affect anadromous salmonid population status and viability. These results support previous studies (Mantua et al. 1997, Zabel et al. 2006) indicating that ocean conditions were important for at least some species of anadromous salmonids. In addition, the inclusion of water travel time as an indicator of freshwater conditions and a significant predictor of estuarine/early ocean survival suggests that environmental effects on salmonid viability may not be restricted to ocean environments. Indeed, it appears that freshwater flows and temperatures affect population status for Snake River spring summer Chinook salmon (Crozier et al. in press), and that WTT explains some variation in SARs for that ESU (Schaller et al. 2007). These ocean and freshwater effects are generally similar across upper Columbia and Snake Interior Columbia ESUs in magnitude and sign. However, the effects differ in magnitude for the Mid Columbia River steelhead ESU, which has considerably poorer data quality and is a population group that traverses fewer dams during its seaward migration.

As with most ecological modeling efforts, there are several unavoidable sources of uncertainty that affect the interpretation of these results. First, available time series of spawners and of smolts for the Snake River populations tend to be substantially longer than those available for the Upper and Middle Columbia River populations. This means that there is greater uncertainty in both the freshwater survival relationship (Beverton-Holt fits) and in the fits to climate-related indicators for Upper and Middle Columbia River ESUs than for Snake River ESUs. This is particularly true for Mid-Columbia steelhead. Second, because the time series for Little Salmon River steelhead was available for only a portion of the population (the Rapid River), the Beverton-Holt fits estimate a lower capacity than is likely for the defined population. The large number of hatchery-origin spawners in other areas within the population make adjusting the capacity of this population problematic. Finally, the uncertainty of other input parameters affects the final results. While we have worked to obtain the best model parameters available, there are several parameters for which only one estimate is available: adult ocean survival, parr-smolt survival (density-independent survival in the freshwater stage), and survival during downstream migration after changes proposed in FCRPS BiOp negotiations are implemented. Any errors in these estimates will be reflected in our results as well.

Under modeled conditions, when survival through the hydropower corridor is changed to reflect current and projected survival scenarios, population productivity is affected in small, but significant ways. This is simply a result of the level of survival improvement achieved with the recent and proposed hydro operations scenarios. Again this effect varies across ESUs, with some populations responding negatively to scenarios that improve conditions for other ESUs. There is also a significant interaction between survival in the hydropower corridor and environmental scenarios. Improvements in the hydropower corridor appear to translate into higher SARs under environmental scenarios incorporating historical conditions.

### 1. Differential Responses to Environmental and Hydropower Scenarios

There are a variety of potential biological reasons that might lead to a differential response of populations/ESUs to environmental and hydropower scenarios. In addition, there was considerable variation in data available to estimate annual return rates and life stage survivals among the populations considered in this analysis. For example, direct estimates of the annual smolt to adult return rates are available for Snake River spring/summer chinook and steelhead outmigrations extending back to 1966. Estimates of smolt to adult return for the Wenatchee population include direct estimates for survivals from a major production area in the drainage for outmigrations starting with the

1992 outmigration. That series was extended back to 1981 using a regression on available smolt to adult survival rate estimates for Leavenworth Hatchery releases. The Umatilla steelhead SAR series is extrapolated from an even shorter series of direct estimates (1995 to present), and the extrapolations are based on comparisons of annual adult return estimates to smolt production numbers extrapolated using a fitted smolt production function. The relatively short time series for Umatilla steelhead in particular means that some of these results should be interpreted with caution. While these results reflect available data, longer time series might change currently detectable patterns.

### *1.1 Differential response to environmental scenarios*

Keeping that uncertainty in mind, there are still a number of potential explanations for the observed differences. For example, salmonid populations across large geographic areas are known to respond differentially to ocean conditions. Alaskan salmonids, for instance, tend to respond positively to PDO conditions that are unfavorable for Columbia River salmonids (Mantua et al. 1997). Different marine distributions may explain some of the differences seen between Columbia River populations. Different marine distributions may explain some of the differences in responses seen among Columbia River populations. Unfortunately, although substantial numbers of steelhead are tagged prior to juvenile release, recoveries in ocean fisheries are relatively rare. However, ocean sampling studies indicate that steelhead originating in Pacific Northwest tributaries exhibit a strong northward migration during their first year in the ocean and may migrate further offshore than juveniles of other salmonids (Pearcy et al. 1988).

Our environmental scenarios also included Water Travel Time (WTT) which is a measure of the average time it takes for water particle to move through a river reach during a specified time period. WTT is a function of reservoir volume and flow, and has increased historically with mainstem dam construction, water depletion and hydropower storage, which stores spring runoff to release at other times of the year (Raymond 1979, Berggren and Filardo 1993, Schaller et al. 1999). For a fixed reservoir volume, it reflects overall flow in the basin, and thus is largely an indicator of freshwater climate (e.g. precipitation). Different areas of the Columbia Basin may be affected differently by large or small-scale climate patterns, with some areas receiving different impacts and benefits from particular patterns than others (Crozier and Zabel 2006). Similarly, WTT reflects conditions for the juvenile fish migration corridor, including both climate conditions and potential impacts of the hydrosystem. The inclusion of WTT as a significant predictor of estuarine-early ocean survival does suggest that some element of these fishes' early experience – local climate (precipitation or temperature), tributary and mainstem flow, hydrosystem conditions (number of dams) or estuarine conditions influenced by flow – affects their survival in later life stages. Any combination of these options is plausible. Precipitation and temperature in freshwater environments has the potential to affect fish condition (REF). Flow has the potential to affect timing of arrival (Achord et al. 2007) and energy expenditure during downstream migration by determining travel time through the hydrosystem (Berggren and Filardo 1993). In fact, timing of arrival at Bonneville Dam appears to affect survival in the ocean for Snake River spring/summer Chinook salmon (Scheuerell and Zabel 2006). The construction of the hydrosystem also affected flow patterns, and may similarly affect arrival timing and energy expenditure (Budy et al. 2002). This may be one mechanism by which the hydrosystem exerts latent mortality on these fishes (Independent Science Advisory Board 2007). Finally, the physical conditions in Columbia River plume have been shown to affect juvenile salmonid distribution (Robertis et al. 2005) and food availability (Morgan et al. 2005). If flow or other WTT correlates affect plume conditions, marine survival could be altered in response to this indicator.

While it is likely impossible to measure the absolute magnitude of any latent mortality attributable to the hydrosystem or its operation (Independent Science Advisory Board 2007), we intend to conduct sensitivity analyses to identify key life stages and describe the response to a wide range of reductions in mortality in the estuarine/early ocean phase – the life stage that implicitly includes any latent mortality in our modeling framework. We anticipate that, like other modeling efforts (Kareiva et al. 2000, Wilson 2003, Zabel et al. 2006), population productivity will be sensitive to reductions in mortality at early life stages – particularly the estuarine/early ocean stage and the freshwater stage.

Importantly, we used the ESU average smolt-to-adult return rate, derived at Lower Granite Dam, to develop environmental relationships for Snake River ESUs. There may be differences between populations in this rate. For instance, as above, arrival timing at Bonneville Dam, for instance, affects SAR (Scheuerell and Zabel 2006). Stream-type Chinook salmon juvenile migrants arrive at Lower Granite Dam at different times, depending on stream elevation (Achord et al. 2007) and distance from the dam (ICTRT unpublished analysis). This likely affects their arrival timing at Bonneville as well. Using the average SAR, then, provides a reasonable estimate of the likely response for

Snake River populations, but should not be regarded as an absolute response for the all populations within the basin. Clearly, both the quality of the response to environmental factors across ESUs and populations and the mechanism of that response are ripe for further research.

### *1.2 Differential response to hydropower scenarios*

Differential ESU/population responses to hydropower scenarios appear to be affected by the specific hydropower configuration and the species' life history.

Snake River steelhead appear to respond negatively to actions that benefit Snake River spring/summer Chinook. This effect holds over both the "Current Operations" scenario, which is based on observed survival rates, and in the "Proposed BiOp" scenario, for which we used Compass model projections. This impact on steelhead may result from biological differences in response to spill and transportation in comparison with Chinook salmon. Current Operations and the proposed action, in comparison with the "Baseline" scenario both emphasize spill. Steelhead survive relatively better under at least some operations and flow regimes when transported than do Chinook salmon (Williams et al. 2005, Berggren et al. 2006); the loss of transportation may thus be a net cost to that ESU. Further, steelhead inriver survival is somewhat lower than that of Chinook, perhaps due to increased predation by birds (Williams et al. 2005) and an apparently greater influence of water velocity and spill on survival (Schaller et al. 2007).

Overall, the Upper Columbia spring Chinook population we modeled appears to have a lower productivity than Snake River populations and Upper Columbia spring Chinook show a slightly larger proportional improvement to both Current Operations and the Proposed BiOp scenario than do Snake River spring/summer Chinook. This difference is likely driven by configuration differences – there is no transport program for Upper Columbia salmonids, so improvements to in-river survival affect the entire population, rather than just a portion of it, as they do for Snake spring/summer Chinook. In addition, changes to the Upper (or Mid-) Columbia hydropower projects under the Public Utility District's Habitat Conservation Plan may have contributed to the improvement seen.

The Umatilla River population (Mid-Columbia steelhead) had a response that was not as strong as that of the Chinook populations, but followed the same general pattern of increased productivity under Current Operations and the Proposed BiOp scenarios. This difference from the Snake River steelhead population may be driven by the lack of transportation for this ESU, as well as a shorter mainstem migration and smaller number of dams that it must traverse. As noted above, recent studies have indicated relatively high and variable mortality levels associated with the migration from Three Mile Dam in the lower Umatilla River (the point at which annual smolt production was measured in the matrix model assessments) and John Day Dam in the mainstem Columbia River. Estimates of annual survivals for this reach are not available for the years used in reconstructing the Umatilla SARs in this analysis. Annual variations in mortality rates in this reach that are not accounted for could obscure or bias estimates of the effects of ocean conditions and mainstem hydropower operations derived from our analyses.

Again, available data for this population are not strong, and these results may reflect the uncertainty associated with its relatively short time series.

### *1.3 Interaction between hydropower and climate scenarios*

In general, populations/ESUs had a greater increase in productivity to hydropower scenarios (Current Operations, Projected BiOp, 100% Survival) under the Historical climate scenario (favorable for all but the Umatilla River (Mid-C) steelhead) than under the other climate scenarios. This suggests that the improved marine survival in favorable climate conditions allows the population to exploit improved in-river survivals more fully.

## 2. Implications for Conservation Planning

Our results provide a number of important considerations for efforts to conserve and restore anadromous Pacific salmonids in the Interior Columbia Basin.

First, the difference in calculated productivity over simulations of differing durations raises an area of caution for the application of these results. Productivity calculated over shorter simulations was typically larger than that calculated over a longer time period. As mentioned above, this is because smaller growing populations are less affected by density dependence than larger ones. The longer (100 year) runs reflect populations that have typically reached some type of equilibrium level. Therefore, we believe the 25 year runs are appropriate for management applications that are directed at alleviating short term risks, while the 100 year runs are more appropriate for long term recovery plans and efforts to achieve population viability. Again, the changes estimated here should be used for planning – to estimate the relative magnitude of additional needed changes, of likely responses to different kinds of actions, the likelihood of reaching viability criteria – rather than as absolute indicators of population status or any change that will be achieved or that is needed.

From the perspective of anadromous salmonid conservation planning, one of the most important results from this work is the differential response of ESUs to climate and hydropower scenarios. Mid-Columbia steelhead appear to respond less strongly to environmental conditions that benefit the other modeled ESUs. [But note that only a short time-series is available for Mid-Columbia fish, increasing the uncertainty and reducing the reliability of this response.] Similarly, Snake River spring/summer Chinook salmon productivity is apparently improved by hydropower operations that have a negative effect on Snake River steelhead. These differences in response mean that conservation plans and actions must consider the effects across ESUs and not just on a single target ESU. Without this comprehensive perspective, conservation planners run the risk of inadvertently endangering or worsening the conditions of other ESUs.

Similarly, the interaction between response to hydropower and environmental scenarios suggests that improvements attributable to the hydropower system must be evaluated in context of environmental conditions. The greater response in life-cycle survival to hydropower scenarios under the historical climate regime than under other climate scenarios indicates that without such consideration, the overall benefit of hydropower actions may be mis-estimated.

Climate's large effect on population productivity indicates that conservation planning for these fishes will also need to consider climate conditions. Stream-type Chinook, in particular, appear to be strongly affected by variations in climate conditions (Figure 9, Appendix A), and conditions associated with a warmer PDO cycle have an especially large impact on productivity for these ESUs. While it is unclear what future global climate change will bring, it is clear that conservation strategies that consider the range of potential environmental regimes, that are most effective across that range, and that account for differential ESU response to those regimes will be most robust. A range of possible future climate conditions should also be considered when evaluating the effectiveness of particular recovery actions (e.g. improving tributary passage).

Our results also indicate that the level of proposed changes to survival through the hydropower system alone, even in environmental periods with a positive effect, are not likely to be sufficient to meet viability goals for most populations. Only substantially greater survival during juvenile migration results in population viability for abundance and productivity in this modeling framework for most populations. With anticipated improvements to juvenile migration survival, only the South Fork Salmon River and the Catherine Creek (under the optimistic, high hatchery fraction removed scenario) populations meet those criteria, and then only under the historical climate scenario. [However, the South Fork Salmon River population is close to meeting viability criteria under the "Projected BiOp" hydro and "Baseline" climate scenarios.]

Key to achieving viability for many listed populations will be both gaining greater understanding of anthropogenic and natural impacts on population productivity and abundance and implementing actions that improve survival at other life stages. Given the uncertainty associated with future climate conditions, it is important to continue efforts to increase survivals through actions that could additionally affect survival outside of the hydropower corridor, including improvements to tributary habitat conditions and actions aimed at further reductions in potential latent mortality associated with the range of hydropower system effects. Importantly, such survival increases outside the hydropower corridor may functionally also increase capacity, if the populations are capacity-limited by habitat quality, habitat quantity, predation or other factors.

This is not to say that past and proposed changes in the hydropower system are not worthwhile, at least for some ESUs. The substantial difference between productivity under the Baseline and Current Operations or Proposed BiOp for Snake River spring/summer Chinook salmon indicates that these past improvements have been important for this ESU. Similarly, while increases in productivity due to the proposed BiOp actions are smaller than those under favorable environmental scenarios, changes to the hydropower system do affect all populations within an ESU, unlike many other conservation actions available to planners. The trade-offs between cost, effect on multiple ESUs and range of effect will need to be evaluated carefully in these conservation decisions.

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# Appendix A.

Table A-1: Model selected to estimate $s_3$ survival of Snake River Spring/Summer Chinook. Included are the top five models, chosen by AIC value, grouped by predictor types. Intercept and coefficient values are presented (with their standard errors in parentheses) and their significances indicated by the following symbolization ($p \leq 0.001$ (***); $0.001 < p \leq 0.01$ (**); $0.01 < p \leq 0.05$ (*); $0.05<p\leq0.1$ (•); $0.1<p\leq1.0$ ( )).

| | | | Upwelling | | | | PDO | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Intercept | WTT | UP SEP | UP JUN | UP MAY | UP APR | PDO SEP | PDO JUN | PDO MAY | PDO APR | NP | AIC | $R^2$ |
| Model Selected | -1.2087 (0.2834) *** | -0.1007 (0.0154) *** | | | | 0.0185 (0.0050) *** | -0.3130 (0.1215)* | | | | 3 | -1.748 | 0.735 |
| PDO, Upwelling, and WTT | -1.2087 (0.2834) *** | -0.1007 (0.0154) *** | | | | 0.0185 (0.0050) *** | -0.3130 (0.1215)* | | | | 3 | -1.748 | 0.735 |
| | -1.4199 (0.2823)*** | -0.0821 (0.0158) *** | | | | 0.0161 (0.0056) ** | | | -0.2828 (0.1180)* | | 3 | -0.913 | 0.728 |
| | -1.3919 (0.2991) *** | -0.0868 (0.0166) *** | | | | 0.0204 (0.0054) *** | | | | -0.1913 (0.1259) | 3 | 2.52 | 0.693 |
| | -1.0457 (0.3736) ** | -0.0975 (0.0167) *** | | | -0.0066 (0.0047) | 0.0262 (0.0051) *** | | | | | 3 | 2.845 | 0.69 |
| | -1.2948 (0.3124) *** | -0.0860 (0.0177) *** | | | | | -0.2871 (0.1418)• | | -0.3470 (0.1218) ** | | 3 | 2.918 | 0.689 |
| PDO and Upwelling | -2.7022 (0.1662) *** | | | | | 0.0097 (0.0076) | | 0.3794 (0.2611) | -0.7889 (0.2844)* | | 3 | 17.94 | 0.478 |
| | -2.7524 (0.1660) *** | | | | | 0.0103 (0.0078) | | | -0.4448 (0.1609)* | | 2 | 18.291 | 0.434 |
| | -2.7333 (0.1653) *** | | | | | 0.0075 (0.0081) | | | -0.8664 (0.3841)* | 0.4721 (0.3913) | 3 | 18.65 | 0.465 |
| | -2.5641 (0.2130) *** | | -0.0069 (0.0084) | | | | | | -1.0473 (0.3368) ** | 0.5740 (0.3761) | 3 | 18.857 | 0.461 |
| | -2.5187 (0.2773) *** | | | | -0.0044 (0.0062) | | | | -1.0996 (0.3477) ** | 0.6075 (0.3797) | 3 | 19.042 | 0.458 |
| PDO only | -2.6223 (0.1514)*** | | | | | | | 0.4942 (0.2552)• | -1.5920 (0.4272) *** | 0.7131 (0.3624)• | 3 | 15.583 | 0.519 |
| | -2.6829 (0.1558)*** | | | | | | | | -1.0402 (0.3346) ** | 0.5767 (0.3738) | 2 | 17.635 | 0.447 |
| | -2.6348 (0.1594)*** | | | | | | | 0.3965 (0.2638) | -0.9178 (0.2689) ** | | 2 | 17.76 | 0.444 |
| | -2.6833 (0.1597) *** | | | | | | | | -0.5653 (0.1344) *** | | 1 | 18.175 | 0.396 |
| | -2.6614 (0.1614) *** | | | | | | 0.1258 (0.2021) | | -1.2045 (0.4293) ** | 0.7124 (0.4366) | 3 | 19.189 | 0.455 |

Table A-2: Model selected to estimate $s_3$ survival of Wenatchee River Spring Chinook (Upper Columbia River Spring Chinook ESU). Included are the top five models, chosen by AIC value, grouped by predictor types. Intercept and coefficient values are presented (with their standard errors in parentheses) and their significances indicated by the following symbolization ($p \leq 0.001$ (***); $0.001 < p \leq 0.01$ (**); $0.01 < p \leq 0.05$ (*); $0.05 < p \leq 0.1$ (•); $0.1 < p \leq 1.0$ ( )).

| | | | Upwelling | | | | PDO | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Intercept** | **WTT** | **UP SEP** | **UP JUN** | **UP MAY** | **UP APR** | **PDO SEP** | **PDO JUN** | **PDO MAY** | **PDO APR** | **NP** | **AIC** | **$R^2$** |
| **Model Selected** | -1.3046 (0.6133)* | -0.1765 (0.0422) *** | | | -0.0113 (0.0064)• | 0.0363 (0.0078) *** | | | | | 3 | 8.271 | 0.6944 |
| **PDO, Upwelling, and WTT** | -1.3046 (0.6133)* | -0.1765 (0.0422) *** | | | -0.0113 (0.0064)• | 0.0363 (0.0078) *** | | | | | 3 | 8.271 | 0.694 |
| | -1.5351 (0.6334)* | -0.1810 (0.0445) *** | | | | 0.0350 (0.0082) *** | | | | | 2 | 9.804 | 0.638 |
| | -1.3559 (0.6525)• | -0.1870 (0.0447) *** | | | | 0.0306 (0.0092) ** | | -0.1795 (0.1672) | | | 3 | 10.426 | 0.661 |
| | -1.2769 (0.6855)• | -0.1970 (0.0474) *** | | | | 0.0320 (0.0088) ** | -0.1666 (0.1686) | | | | 3 | 10.63 | 0.658 |
| | -1.3104 (0.6801)• | -0.1851 (0.0449) *** | | | | 0.0298 (0.0100) ** | | | -0.2023 (0.2174) | | 3 | 10.761 | 0.656 |
| **PDO and Upwelling** | -3.6862 (0.3150) *** | | | | -0.0130 (0.0089) | 0.0336 (0.0108) ** | | | | | 2 | 21.126 | 0.38 |
| | -4.0201 (0.2230) *** | | | | | 0.0321 (0.0111) ** | | | | | 1 | 21.476 | 0.307 |
| | -3.5140 (0.3719)*** | | | | -0.0154 (0.0094) | 0.0288 (0.0122)* | | -0.2033 (0.2296) | | | 3 | 22.18 | 0.407 |
| | -3.4026 (0.4512)*** | | | | -0.0155 (0.0094) | 0.0271 (0.0132)• | | | -0.2631 (0.2979) | | 3 | 22.184 | 0.407 |
| | -3.9690 (0.4543) *** | | | 0.0101 (0.0116) | -0.0168 (0.0100) | 0.0354 (0.0111) ** | | | | | 3 | 22.212 | 0.407 |
| **PDO only** | -3.7293 (0.3248) *** | | | | | | | | -1.2636 (0.4944)* | 1.0227 (0.5493)• | 2 | 24.289 | 0.279 |
| | -3.6782 (0.3365) *** | | | | | | 0.1861 (0.2547) | | -1.4428 (0.5578)* | 1.1003 (0.5666)• | 3 | 25.639 | 0.301 |
| | -3.6801 (0.3441) *** | | | | | | | | -0.4706 (0.2669)• | | 1 | 25.987 | 0.141 |
| | -3.6596 (0.3681) *** | | | | | | | 0.2050 (0.4654) | -1.5180 (0.7679)• | 1.0704 (0.5724)• | 3 | 26.05 | 0.288 |
| | -3.9000 (0.2864) ** | | | | | | | -0.3375 (0.2270) | | | 1 | 26.858 | 0.104 |

Table A-3: Model selected to estimate Seo survival of Snake River Steelhead. Included are the top five models, chosen by AIC value, grouped by predictor types. Intercept and coefficient values are presented (with their standard errors in parentheses) and their significances indicated by the following symbolization ($p \leq 0.001$ (***); $0.001 < p \leq 0.01$ (**); $0.01 < p \leq 0.05$ (*); $0.05 < p \leq 0.1$ (•); $0.1 < p \leq 1.0$ ( )).

| | | | Upwelling | | | PDO | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Intercept | WTT | UP SEP | UP MAY | UP APR | PDO SEP | PDO JUN | PDO MAY | PDO APR | NP | AIC | $R^2$ |
| **Model selected** | -0.985 (0.262) *** | -0.0405 (0.0137) ** | -0.01486 (0.0047) ** | | | | | -0.9392 (0.1873) *** | 0.6636 (0.1975) ** | 4 | -12.31 | 0.675 |
| **PDO, Upwelling, and WTT** | -0.985 (0.262) *** | -0.0405 (0.0137) ** | -0.01486 (0.0047) ** | | | | | -0.9392 (0.1873) *** | 0.6636 (0.1975) ** | 4 | -12.31 | 0.675 |
| | -1.388 (0.264) *** | -0.032 (0.0148)* | | | | 0.2735 (0.1118)* | | -1.2866 (0.2324) *** | 0.9502 (0.2223) *** | 4 | -8.45 | 0.637 |
| | -1.277 (0.280) *** | -0.0397 (0.0156)* | | | | | | -0.9866 (0.2126) *** | 0.7503 (0.2227) ** | 3 | -4.09 | 0.564 |
| | -0.938 (0.302)** | -0.0415 (0.0158)* | -0.01702 (0.0053) ** | | | | | -0.3685 (0.0912) *** | | 3 | -3.13 | 0.552 |
| | -1.174 (0.346)** | -0.0416 (0.0162)* | | -0.00209 (0.0041) | | | | -1.0066 (0.2186) *** | 0.7557 (0.2256) ** | 4 | -2.4 | 0.568 |
| **PDO and Upwelling** | -1.711 (0.132) *** | | -0.01146 (0.0051)* | | | 0.255 (0.1130)* | | -1.2912 (0.2303) *** | 0.8791 (0.2261) *** | 4 | -8.84 | 0.641 |
| | -1.606 (0.144) *** | | -0.01486 (0.0051) ** | | -0.00718 (0.0053) | | | -1.1763 (0.2368) *** | 0.7732 (0.2292) ** | 4 | -5.44 | 0.604 |
| | -1.669 (0.139) *** | | -0.01461 (0.0052) ** | | | | | -1.015 (0.2075) *** | 0.6764 (0.2207) ** | 3 | -5.36 | 0.58 |
| | -1.88 (0.108) *** | | | | -0.00518 (0.0054) | 0.3136 (0.1163)* | | -1.5049 (0.2637) *** | 1.0591 (0.2433) *** | 4 | -4.44 | 0.593 |
| | -1.845 (0.170) *** | | | -0.00221 (0.0040) | | 0.3391 (0.1198) ** | | -1.4393 (0.2526) *** | 1.0129 (0.2386) *** | 4 | -3.73 | 0.584 |
| **PDO only** | -1.922 (0.099) *** | | | | | 0.3247 (0.1156) ** | | -1.3995 (0.2395) *** | 0.9962 (0.2340) *** | 3 | -5.38 | 0.58 |
| | -1.9 (0.103) *** | | | | | 0.3212 (0.1163) ** | 0.1381 (0.1681) | -1.5403 (0.2955) *** | 1.0213 (0.2372) *** | 4 | -4.15 | 0.589 |
| | -1.942 (0.109) *** | | | | | | | -1.0601 (0.2279) *** | 0.7614 (0.2410) ** | 2 | 0.56 | 0.473 |
| | -1.918 (0.113) *** | | | | | | 0.155 (0.1850) | -1.2222 (0.2998) *** | 0.7924 (0.2449) ** | 3 | 1.78 | 0.485 |
| | -1.954 (0.122) *** | | | | | | | -0.4024 (0.1048) *** | | 1 | 8.06 | 0.309 |

Table A-4: Model selected to estimate Seo survival of Umatilla steelhead (Mid-Columbia River steelhead ESU). Included are the top five models, chosen by AIC value, grouped by predictor types. Intercept and coefficient values are presented (with their standard errors in parentheses) and their significances indicated by the following symbolization ($p \leq 0.001$ (***); $0.001< p \leq 0.01$ (**); $0.01 < p \leq 0.05$ (*); $0.05<p\leq0.1$ (•); $0.1<p\leq1.0$ ( )).

| | Intercept | WTT | Upwelling | | | | PDO | | | | NP | AIC | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | UP SEP | UP JUN | UP MAY | UP APR | PDO SEP | PDO JUN | PDO MAY | PDO APR | | | |
| **Model selected** | -2.4164 (0.2075) *** | | | | | | | 0.4454 (0.2282)• | -1.6550 (0.4028) *** | 1.2611 (0.2996) *** | 3 | -0.68 | 0.548 |
| **PDO, Upwelling, and WTT** | -2.1453 (0.6891) ** | -0.0666 (0.0989) | | | | | | | -1.0500 (0.2893) ** | 1.1050 (0.3153) ** | 3 | 3.01 | 0.461 |
| | -1.4535 (0.8230) • | -0.1336 (0.1119) | -0.0124 (0.0076) | | | 0.0184 (0.0078)* | | | | | 3 | 7.84 | 0.322 |
| | -1.935 (0.7817)* | -0.1351 (0.1127) | | | | 0.0215 (0.0083)* | | | | 0.3220 (0.2039) | 3 | 8.05 | 0.315 |
| | -1.9026 (0.8117)* | -0.1096 (0.1160) | | | | 0.0170 (0.0081)* | | | | | 2 | 8.92 | 0.214 |
| | -1.7261 (0.8502) • | -0.1154 (0.1175) | | | -0.0052 (0.0066) | 0.0176 (0.0082)* | | | | | 3 | 10.17 | 0.242 |
| **PDO and Upwelling** | -2.1818 (0.2918) *** | | -0.0125 (0.0068) • | | | | | | -1.1195 (0.2691) *** | 1.0246 (0.2951) ** | 3 | -0.23 | 0.538 |
| | -2.1240 (0.3524) *** | | | -0.0103 (0.0065) | | | | | -1.1711 (0.2818) *** | 1.1451 (0.2994) ** | 3 | 0.69 | 0.517 |
| | -2.6403 (0.2202) *** | | | | | 0.0059 (0.0091) | | | -0.9186 (0.3632)* | 1.0209 (0.3410) ** | 3 | 3.04 | 0.46 |
| | -2.5107 (0.2847) *** | | | | -0.0023 (0.0059) | | | | -1.0599 (0.2912) ** | 1.0817 (0.3234) ** | 3 | 3.37 | 0.452 |
| | -2.3965 (0.2343) *** | | -0.0112 (0.0076) | | | 0.0172 (0.0078)* | | | | | 2 | 7.53 | 0.265 |
| **PDO only** | -2.4164 (0.2075) *** | | | | | | | 0.4454 (0.2282) • | -1.6550 (0.4028) *** | 1.2611 (0.2996) *** | 3 | -0.68 | 0.548 |
| | -2.5508 (0.1946) *** | | | | | | 0.2357 (0.1440) | | -1.2817 (0.3032) *** | 1.2168 (0.3047) *** | 3 | 0.49 | 0.522 |
| | -2.5885 (0.2020) *** | | | | | | | | -1.0620 (0.2843) ** | 1.1051 (0.3105) ** | 2 | 1.56 | 0.447 |
| | -2.4989 (0.2547) *** | | | | | | | | -0.2081 (0.1938) | | 1 | 10.75 | 0.057 |
| | -2.8065 (0.2508) *** | | | | | | | | | 0.1263 (0.2160) | 1 | 11.62 | 0.018 |

# Appendix B. Comparison of the relationship between estuary-early-ocean survival and a climate index over different time periods.

## Overview

Early in the development of this matrix model, we tested the hypothesis that the relationship between climate and estuary and early ocean survival may have changed after the construction of the Snake River dams. At that stage, we were using a climate model that used only PDO as predictor variables, and only had a model developed for Snake River spring/summer Chinook salmon. To investigate this possible change, we used monthly PDO from two time periods -- 1966-2000 (entire time series) and 1978-2000 (post- Lower Snake River dams only) – as predictors of estuarine and early ocean survival.

We found that regressions from the different time periods, even incorporating alternative methods of calculating $s_3$, resulted in very similar regression coefficients and proportion of variation explained for this ESU (Tables B-1 to B-4, Figure B-1). We therefore concluded that it was unlikely that the relationship between this indicator and survival at this stage had changed with the construction of the dams, and continued to derive the environmental-$s_3$ relationship using the entire time series of SARs.

Table B-1. Regression results for 1966-2000:

Residual Standard Error = 0.5044, Multiple R-Square = 0.7404
N = 35, F-statistic = 29.4772 on 3 and 31 df, p-value = 0

| | coef | Std. err | t. stat | p. value |
|---|---|---|---|---|
| Intercept | -2.6067 | 0.0938 | -27.7898 | 0.0000 |
| April PDO | 0.7831 | 0.2036 | 3.8456 | 0.0006 |
| May PDO | -1.7570 | 0.2493 | -7.0475 | 0.0000 |
| June PDO | 0.5171 | 0.1539 | 3.3604 | 0.0021 |

Table B-2. Regression results for 1978-2000:

Residual Standard Error = 0.4414, Multiple R-Square = 0.7251
N = 23, F-statistic = 16.7082 on 3 and 19 df, p-value = 0

| | coef | Std. err | t. stat | p. value |
|---|---|---|---|---|
| Intercept | -2.7061 | 0.1590 | -17.0225 | 0e+00 |
| April PDO | 1.0671 | 0.2240 | 4.7644 | 1e-04 |
| May PDO | -1.9391 | 0.3027 | -6.4055 | 0e+00 |
| June PDO | 0.5585 | 0.1706 | 3.2738 | 4e-03 |

Table B-3. Regression results for 1966-2000 (minus 1985-1991):

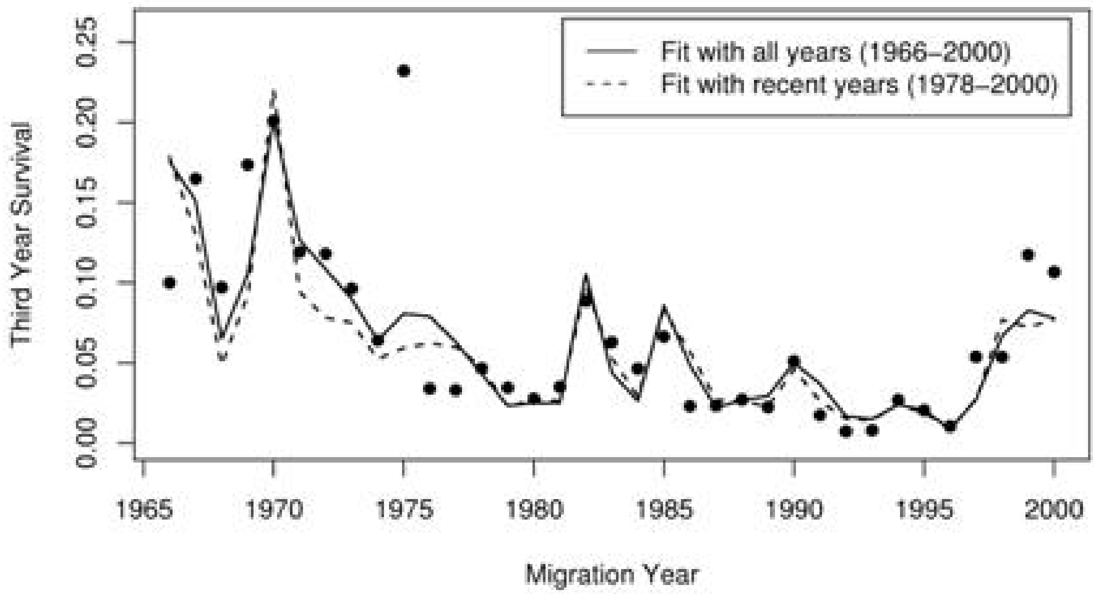
Residual Standard Error = 0.5141, Multiple R-Square = 0.7584
N = 28, F-statistic = 25.118 on 3 and 24 df, p-value = 0

| | coef | Std. err | t. stat | p. value |
|---|---|---|---|---|
| Intercept | -2.5414 | 0.1030 | -24.6702 | 0.0000 |
| April PDO | 0.7277 | 0.2420 | 3.0073 | 0.0061 |
| May PDO | -1.6559 | 0.2851 | -5.8084 | 0.0000 |
| June PDO | 0.4499 | 0.1704 | 2.6396 | 0.0144 |

Table B-4. Regression results for 1966-2000 (with St = D * 0.98):

Residual Standard Error = 0.5031, Multiple R-Square = 0.7396
N = 35, F-statistic = 29.3486 on 3 and 31 df, p-value = 0

| | coef | Std. err | t. stat | p. value |
|---|---|---|---|---|
| Intercept | -2.5975 | 0.0936 | -27.7618 | 0.0000 |
| April PDO | 0.7827 | 0.2031 | 3.8530 | 0.0005 |
| May PDO | -1.7496 | 0.2487 | -7.0357 | 0.0000 |
| June PDO | 0.5127 | 0.1535 | 3.3404 | 0.0022 |



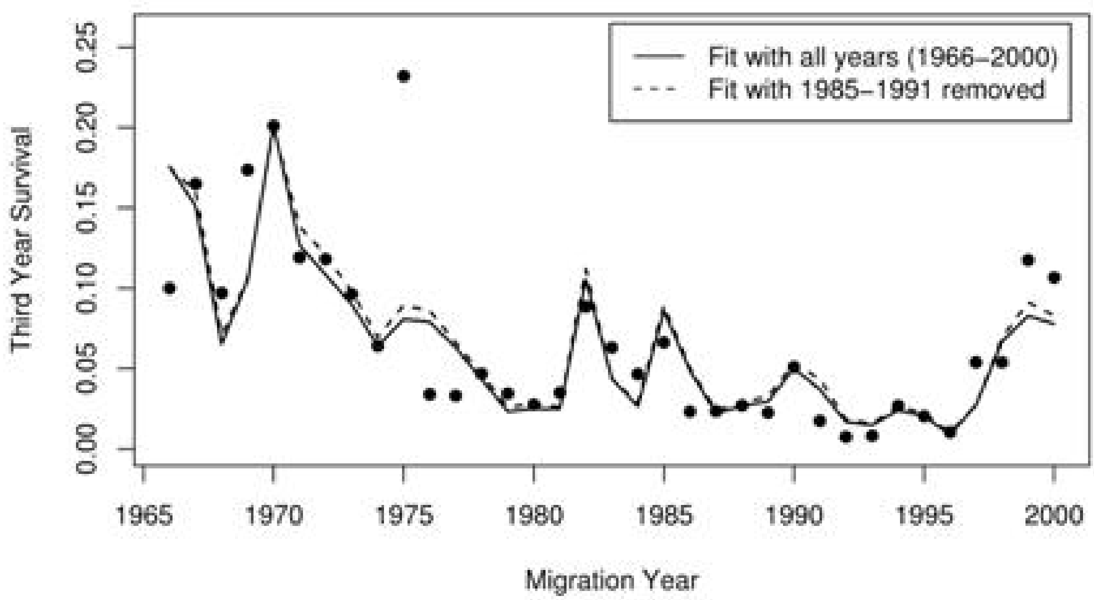




Figure B-1. Comparisons of various fits to the data. In both plots, the solid line is the fit to the full time series (1966-2000). In the top plot, the dashed line is the model prediction using the recent time series, 1978-2000. In the bottom plot, the dashed line is the model prediction using the time series with 1985-1991 omitted. In both these cases, the model was fit using the reduced time series, but then applies to the fulltime series.

## Appendix C. Alternative approaches to estimating $s_3$ (estuarine and early ocean survival).

### Overview

We estimated estuarine and early ocean survival ($s_3$) by removing "known" survival rates from total smolt-to-adult survival, as described in the Methods section of the main report. These "known" components included juvenile downstream survival (including in-river survival, and where relevant, proportion transported and 'D' or differential transportation mortality), adult ocean survival, adult upstream migration survival, and harvest. However, there were approaches to a number of these parameters that we did not use in the final model that we implemented for Snake River spring/summer Chinook salmon. In general, we found that these alternative approaches made relatively small differences in $s_3$; we employed in our final model methods that best matched actual conditions.

### Snake River spring/summer Chinook salmon

*Upstream passage survival*

We evaluated two approaches for estimating upstream migration survival in the Columbia, or the Columbia and Snake. Smolt-to-adult returns (SARs) represented smolts at the uppermost dam (Lower Granite since 1975) and adult returns to the upper dam plus harvest in the mainstem Columbia River (Williams et al. 2005; Petrosky et al. 2001). The estimated age structured returns at the uppermost Snake River Dam (including prior mainstem harvest) were divided by annual upstream passage survival estimates ($s_u$) from Bonneville Dam, 1965-2004, to obtain an estimate of returns to the river mouth.

The first approach expanded the SARs for upstream passage loss assuming a constant upstream passage survival (Su) of 0.794 based on recent (2002-2003 returns) estimates from PIT tag detections (Williams et al. 2005).

The second approach for $s_3$ calibrated the recent tag-based $s_u$ estimates to historical run reconstruction $s_u$ estimates to account for historical changes in upstream passage survival. Two sources of data were used for $s_u$ in this approach. Recent estimates of $s_u$ from PIT tag studies averaged 0.88 (range 0.84 to 0.92) for Snake River wild spring/summer Chinook for 1999-2003. The proportion of Bonneville Dam PIT tags detected at Lower Granite each year was divided by survival rate (1-harvest rate) through the Zone 6 mainstem fishery above Bonneville Dam. The second source of $s_u$ estimates was the US v. Oregon Technical Advisory Committee run reconstruction of upriver spring and summer Chinook adult returns) for all return years, 1965-2004 (E. Tinus, ODFW and H. Yuen, USFWS). Run reconstruction Su estimates for Snake River spring/summer Chinook averaged 0.66 during 1999-2003 (75% of the tag study estimate). We believe that $s_u$ estimated from tag studies are the most accurate, but are for a limited time period after adult passage improvements were implemented (spill pattern management, attraction flows). Therefore, we assumed the run reconstruction Su estimates captured the temporal pattern of the time series, and adjusted the run reconstruction $s_u$ by the ratio between the two methods.

### *D values*

The $s_T$ parameter includes a "delayed differential mortality" of transported fish (from Williams et al. 2005, Berggren et al. 2005), accounting for the fact that transported fish return at lower rates than fish that migrated volitionally. Although this delayed mortality is most likely expressed during the early ocean life stage, we applied it to the downstream migration stage because it simplifies calculation of the early ocean survival term and is mathematically equivalent. We used two approaches to implement estimates of D.

A constant D value (0.553) was assumed for all years in the first approach, based on estimates for 1993-2000 from Williams et al. (2005). However, if 'D' is variable between years, there is the potential that variability has been mis-apportioned.

The second approach to estimating $s_3$ used annual estimates of D for 1994-2001, and sampling from the distribution for years before 1994. Annual D-values of wild spring/summer Chinook for migration years 1994-2002 were obtained from the Comparative Survival Study (Berggren et al. 2005). The geometric mean of D-values was 0.47 (range 0.32 to 0.86), excluding the major drought year of 2001 when D equaled 2.20. For the pre-1993 migration years we sampled from the distribution of D for all years except for major drought years (1973 and 1977) where we assumed the 2001 estimate applied.

We calculated $s_3$ incorporating the alternative upstream survival and D-values.

### *Results and Conclusions*

Estuarine and early ocean survival estimates varied under the alternative approaches (Figure C-1). In migration year 2001, when the estimated D value was 2.20, $s_3$ was larger when fixed values were assumed. It decreased to about 0.013 from the initial estimate of 0.061 when variable values were included. $s_3$ estimates decreased in the other drought years (1973 and 1977) with an assumed high D value when the variable values were used.

In our final model, we used the adjusted values of upstream survival and the variable D-values.

Snake River Steelhead

*Upstream passage survival*

Smolt-to-adult returns (SARs) represented smolts at the uppermost dam (Lower Granite since 1975) and adult returns to the upper dam plus harvest in the mainstem Columbia River (Marmorek et al. 1998; Williams et al. 2005). The estimated age structured returns at the uppermost Snake River Dam (including prior mainstem harvest) were divided by upstream passage survival estimates (Su) from Bonneville Dam, 1965-2004, to obtain an estimate of returns to the river mouth.

Estuarine and early ocean ($s_{eo}$) calculations for the first approach expanded the SARs for upstream passage loss assuming a constant upstream passage survival ($s_u$) of 0.805 based on recent (2001-2003) estimates from PIT tag detections (Williams et al. 2005).

The second approach used the most recent compilation of PIT tag detections from the BiOp Remand. Upstream passage survival estimates from Bonneville Dam to Lower Granite Dam from PIT-tagged Snake River steelhead averaged 0.77 (range 0.68 to 0.82) for 2000-2005. The proportion of Bonneville Dam PIT tags detected at Lower Granite each year was adjusted by the Zone 6 harvest rate. The average $s_u$ value was assumed for the pre-2000 return years because no long-term run reconstruction estimates of $s_u$ were available for steelhead (unlike the case for spring/summer Chinook).

*Transport proportion*

The first approach for $S_{eo}$ calculations used recent estimates of transport proportions from Williams et al. (2005). We developed a relationship between Chinook and steelhead transport proportions for years with data and expanded that to years prior to 1993.

The second approach revised the transport proportion of steelhead smolts from the initial $S_{eo}$ calculations for years prior to 1994 based on available data from Fish Transportation Oversight Team (FTOT) reports (e.g., Ceballos et al. 1993) and Park (1985). Annual estimates of proportion of wild steelhead smolts transported from Snake River dams were obtained from Williams et al. (2005) for migration years 1993-2005 and from FTOT reports for migration years 1985-1992 (e.g., Ceballos et al. 1993). Wild and hatchery steelhead were not counted separately at mainstem dams before 1985. Therefore, annual estimates of total steelhead (wild plus hatchery) transport proportions were from FTOT reports for migration years 1981-1984, and Park (1985) for migration years 1971-1979. Transported smolts were in Lower Granite equivalents, which required expanding the numbers transported from Little Goose Dam by the in-river survival between Lower Granite and Little Goose dams.

*D-values*

The first approach to Seo calculations used an average D value of 0.582 (Williams et al. 2005) for 1994-2000.

The second approach used two alternative D values estimates, the first from NMFS (Williams et al. 2005) for 1994-2000 and the second from Comparative Survival Study (CSS) for 1997-2003 (Berggren et al. 2005). Fixed values were applied to all years because of wide confidence intervals on the annual estimates and large inter-annual variation. The NMFS geometric mean D value was 0.582 (range 0.12 to 1.01). The CSS geometric mean D value was 0.78 (range 0.11 to 2.27).

*Results*

Seo estimates were sensitive to the alternate approaches (Figures C-2, C-3). Using both the NMFS fixed D value (0.582) and the CSS fixed D value (0.78), the revised $s_3$ estimates were lower during 1978-1987 than Seo estimates without adjusted transport proportion and upstream survival values. Diagnostics suggest that the primary cause of the shift in pattern from the initial Seo estimates was from incorporating the FTOT and Park (1985) estimates transport proportions. The change from the initial Seo estimate was greatest using the higher D value (CSS).

We used the adjusted transport proportion, the D-value from Williams et al. (2005) and the adjusted upstream survival rate in our final model.

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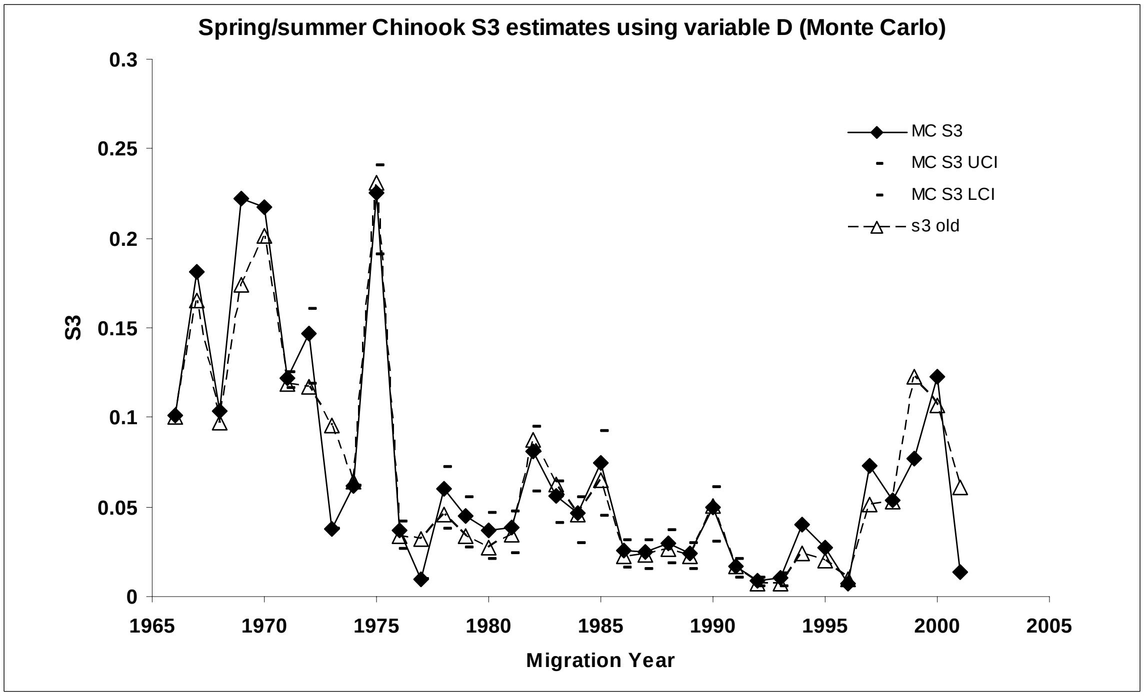


Figure C-1. $S_3$ estimated with variable D and unadjusted upstream survival values ($s_3$ old) and second approach (MC $s_3$) using annual D estimates for 1994-2001 and variable D for earlier years as well as adjusted upstream survival values. Upper and lower 95% confidence intervals are shown (dashes) for years with variable D estimates.

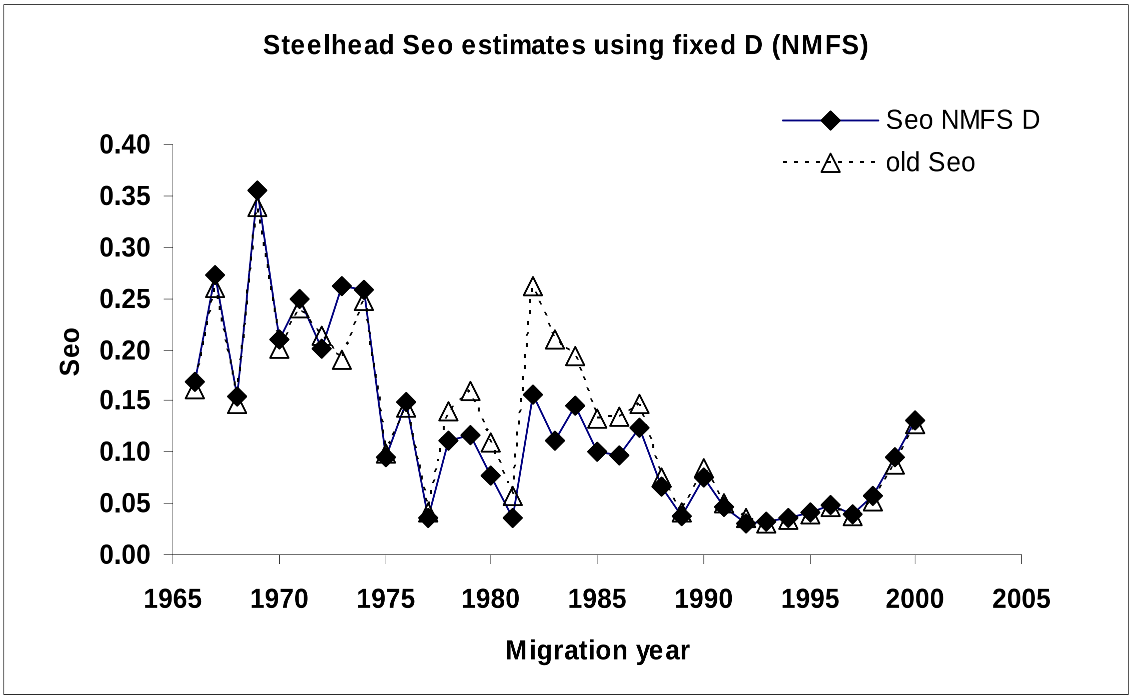


Figure C-2. $S_{eo}$ estimated with fixed D-values, unadjusted transport and unadjusted upstream survival ($S_{eo}$ old) and second approach using fixed estimates of D from NMFS for 1994-2000 (Williams et al. 2005) with adjusted transport and upstream survival values.

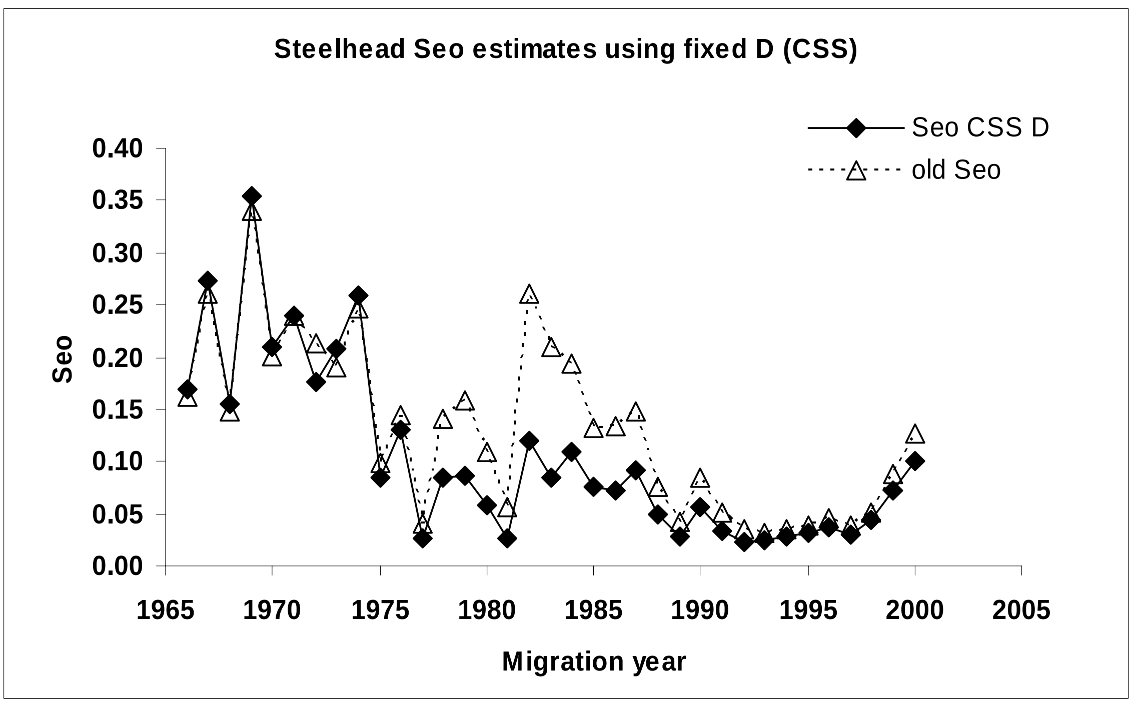


Figure C-3. $S_{eo}$ estimated with fixed D-values and unadjusted transport and upstream survival values ($S_{eo}$ old) and second approach using fixed estimates of D from CSS for 1997-2003 (Berggren et al. 2005) with adjusted transport and upstream survival values.